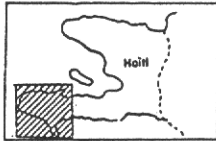


PRECISIONS SUR LA NATURE, LA STRATIGRAPHIE ET L'EXTENSION DE LA FORMATION DE RIVIERE GLACE (PRESQU'ILE DU SUD D'HAÏTI).

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La formation de Rivière Glace a été observée et décrite d'abord par J. Butterlin (1954; 1960) puis par T. Calmus (1983) qui en a proposé le terme. De nature essentiellement détritique, cette formation telle qu'observée dans la localité type, est constituée d'une série rythmique de silt calcaire-argileux, les bancs fins augmentant en proportion à mesure qu'on descend dans la série. D'autres affleurements présentent une séquence silto-gréseuse avec des passées de calcarenites à granoclassement typique des turbidites et des figures de base de bancs.



Localisation du secteur d'étude

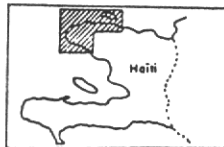
L'âge de la formation se précise: la limite Crétacé-Tertiaire.

Des échantillons prélevés dans deux localités distantes de 40 km environ, ont livré une nannoflore: *Micula prinsii*, *Thoracosphaera* sp. et *Watznaueria barnesae* indiquant le Maestrichtien terminal-Danien (à noter que *Micula prinsii*, forme rare, est un excellent marqueur dont l'apparition n'a duré que 150000 ans environ). Plus au Nord de ces deux localités, un niveau de calcaire gris bleuté, finement détritique, intercalé dans des pelites a fourni des petites globigérines du Danien inférieur, de rares rugoglobigérines, des *Gumbelina* sp. et de gros lagenides rectilignes. L'extension géographique de cette formation dépasse les limites connues. On a observé des affleurements à plus de 50 Km à l'Est et 80 Km à l'Ouest de la localité type. La formation de Rivière Glace, dont l'importance se précise au fur et à mesure de nos investigations, est complexe. Elle semble être l'équivalent de la formation de Beloc.

APERÇU SUR LES TERRASSES PLIO-QUATÉRNAIRES DU NORD-OUEST D'HAÏTI

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Les terrasses plio-quaternaires qui bordent la partie nord-ouest de la côte haïtienne sont parmi les plus spectaculaires du monde. Très nombreuses et exceptionnellement préservées, elles expriment l'instabilité tectonique de la région qui se situe en bordure de la plaque Caraïbe. Leur obliquité par rapport à la limite de cette plaque, leurs altitudes et leurs diverses inclinaisons permettent de mesurer avec précision la déformation de la région.



Localisation du secteur d'étude

Les terrasses ne sont pas uniquement des constructions récifales; en effet, d'après l'observation de coupes naturelles de rivières et de falaises, elles se caractérisent par des formations de pentes importantes (couches détritiques obliques) surmontées de dalles massives plus ou moins construites d'où l'importance de l'érosion marine par rapport à la contribution organique, dans la création des terrasses.

SUBSURFACE GEOLOGY OF RIO MAJADA AND RIO LAPA VALLEYS, PUERTO RICO

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A geophysical study to map the subsurface geology of the Rio Majada and Rio Lapa valleys, located in southern Puerto Rico, was undertaken to delineate geologic controls of the main water supply sources for the Puerto Rico Olympic Committee training facility. Surface geophysical techniques and continuous core samples were used to obtain information about the thickness of the alluvium and gross variations in lithology throughout both valleys.

The seismic refraction sections and electrical resistivity soundings, calibrated with the drill hole lithology, can be divided into three units: 1) alluvial deposits; 2) weathered rocks; 3) unweathered rocks. Alluvium thickness varies from 10 to 35 feet. This thin veneer of alluvium overlies weathered flow breccias and volcanic breccias in the Rio Majada valley; and tuffaceous mudstones, volcanic breccias and pillow lavas in the Rio Lapa valley. The weathering profile is the sequence of layers of materials with different physical properties which have developed in-situ and lies above the unweathered rocks. Three layers within the weathered profile were delineated on the basis of distinct seismic velocity differences, although the irregular and gradational nature of the contacts was poorly defined in the core samples. Weathered volcanic breccias, tuffaceous mudstones and pillow lavas in the Rio Majada and Rio Lapa valleys constitute the most favorable water-bearing units for ground-water development.

LES SEDIMENTS RECENTS DU PLATEAU INSULAIRE GUADELOUPEEN

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Le plateau insulaire de l'archipel guadeloupéen a fait l'objet d'une cartographie détaillée de la couverture sédimentaire meuble et de la morphologie sous-marine, à l'aide de différentes techniques complémentaires: sonar à balayage latéral, sismique réflexion haute résolution, bathymétrie, prélèvements de sédiments à la benne, prises de vue, carottage. La reconnaissance quasi complète a été réalisée.

Les résultats montrent:

- la répartition horizontale des formations: massifs coralliens et ensemble sédimentaire. A l'intérieur de celui-ci, en fonction des coefficients de rétrodiffusion des constituants, différents types de sable ont été identifiés, certains pouvant être affectés par des figures de houle.
- la distribution verticale des accumulations, mettant particulièrement en évidence des chenaux fossiles.

Les documents élaborés sont une référence utile pour toute activité liée au domaine marin: enseignement, aménagement, exploitation des ressources, protection du milieu.

THE CARIBBEAN SOUTH AMERICAN PLATE BOUNDARY IN THE  
CARIBBEAN MOUNTAINS PROVINCE, EASTERN VENEZUELA

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Preliminary results of a structural geologic study of the intermediate P/T metamorphic rocks of the Araya Peninsula, the El Pilar fault zone, and the fold and thrust belt south of the El Pilar fault, are consistent with recent plate-tectonic models for the interaction of the Caribbean and South American lithospheric plates. The rocks of the Araya Peninsula underwent two synmetamorphic phases of isoclinal folding ( $D_{1a}$  and  $D_{1b}$ ) which may have resulted from east-directed tectonic transport. The  $D_{1a}$  and  $D_{1b}$  structures are cross cut by north-south striking listric normal faults/shear zones and kinks ( $D_{1c}$ ) which indicate east-west extension. The next phase of folding ( $D_2$ ) is characterized by tight to open postmetamorphic, east-northeast trending folds, generally verging to the south and generally accompanied by south vergent thrust faults (north vergent folds and thrust faults are relatively rare). The youngest major phase of folding ( $D_3$ ) is characterized by east and west vergent folds, accompanied by east and west vergent thrust faults, respectively. The structures in the fold and thrust belt, south of the El Pilar fault, underwent the last two phases of folding ( $D_2$  and  $D_3$ ) recognized north of the fault. Along the El Pilar fault, upper Tertiary and lower Cenozoic(?) rocks are deformed by  $D_3$  structures. It is proposed that the  $D_{1a}$  and  $D_{1b}$  structures formed in a "transpressional terrane" or a "forearc sliver" as a result of interaction of the Farallon plate with northwestern South America during the mid to Late Cretaceous, and that the  $D_{1c}$  extensional structures are related to Late Cretaceous uplift and gravitational collapse while the terrane was displaced northeastward in a transform margin. The  $D_2$  structures may have formed during mid to late Tertiary time as a result of the eastward passing of the lesser Antilles volcanic arc along the northern margin of South America. The  $D_3$  structures are related to "restraining bends" of the east-west striking strike-slip faults which make up the present plate boundary.

PRESUPUESTO DE SEDIMENTOS, ESPERANZA, VIEQUES, PUERTO RICO  
(1935-1988): RELACIONADO CON LOS CAMBIOS EN LAS CONDICIONES  
CLIMATOLÓGICAS DEL CARIBE

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Estudio de presupuesto de sedimentos en la zona de Esperanza, Vieques, P.R. durante los últimos cincuenta años relacionado con los cambios en las condiciones climáticas en el Caribe. Dinámica de transferencia de sedimentos en el sistema es descrita cualitativa y cuantitativamente, a través del estudio de cambios de perfiles de playa, muestras de sedimentos actuales colectadas mediante dragado y muestras de playa, análisis de patrones de refracción, comparación de contornos de batimetría, medidas de corrientes litorales, estudios de fotografías aéreas del área a escala de 1:2,000 y datos climatológicos de la zona bajo condiciones de eventos promedio normales y anormales. Análisis de las variables del sistema demuestran un incremento en la tasa de erosión durante los últimos veinte años.

SEDIMENT BUDGET, ESPERANZA, VIEQUES, PUERTO RICO (1935-  
1988): RELATED TO CARIBBEAN CLIMATIC CONDITIONS CHANGES

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This paper presents a sediment budget study at Esperanza, Vieques, P.R. The beach equilibrium has changed during the last fifty years of Caribbean climatic changes. Beach sediment dynamics are described both quantitatively and qualitatively using: monthly beach profiles, analyses of beach and nearshore samples, wave refraction plots, bathymetric changes, current measurements, and weather data. Aerial photos at 1:2,000 were used to measure shoreline changes over a 50 year period. Analysis of the data shows a increase in erosion rates for the last twenty years.

GENETIC AND PROCESS MINERALOGIC ASPECTS OF GOLD-QUARTZ VEIN  
MINERALIZATIONS, CORDILLERA OCCIDENTAL, COLOMBIA S.A.

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Hydrothermal gold-quartz mineralizations in the Western Cordillera (Cordillera Occidental) of Colombia are mainly associated with high-plutonic tonalite intrusions of Tertiary age. Polymetallic Pb-Zn-Cu-Au-Ag vein systems and impregnations formed from aqueous phases of mixed formational-magmatic origin with a main and also productive stage between 290-210 °C. Intensively altered wall rocks show pyritic propylitization, also kaolinitization and silicification. Present mining operations are relatively small, and their full potential has not yet been utilized. Initial process mineralogic studies used selected composite samples from various gold-quartz mineralizations in the southern part of the Western Cordillera. Substantial amounts of gold occur as coarse to fine or ultrafine inclusions of native gold in base metal sulfides, i.e., pyrite, chalcopyrite, galena, and sphalerite. Virtually all of the native gold exhibits a distinct light yellow colour indicative of elevated silver concentrations of 15-25 wt%. Particle size analyses of gold indicate a bimodal size distribution, with approximately 30-40 % of the Au occurring in the coarse size (+ 200 mesh) fraction and 60-70 % in the fine to ultrafine size range of -200 to -500 mesh. Silver exhibits a more complex mineralogic occurrence with considerable concentrations associated with Ag-bearing tetrahedrite, pyrrargyrite, sphalerite, chalcopyrite, and galena. High grade zones in various parts of the veins may affect sampling and assaying of drill core, channel, and trench samples. Thus, great care is advised during sampling preparation to minimize severe nugget effects due to coarse gold particle sizes. Gold mineralizations frequently extend into hanging and foot walls of the veins where gold is primarily associated with pyritic-propylitic alteration and mineralization.

Process mineralogy indicates that many vein ores should be amenable to physical pre-concentration methods using gravity devices. It is recommended that any further assessment work on these very attractive mineralizations be guided by such evaluations. Increased recovery rates and higher profitability can be expected.

PALEOGENE ACCRETION AND SUSPECT TERRANES IN SOUTHERN COSTA RICA (OSA, BURICA, CENTRAL AMERICA)

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Oceanic Basement and associated deep water sediments of the Osa and Burica Peninsulas and the Golfo Dulce area have been globally included with the Nicoya Complex by most authors. Our field studies of the last 5 years lead to a separation of 3 units, which are distinct from the Nicoya Complex and separated from each other by Neogene to Recent fault systems. Each of the units is characterized by a distinct Late Cretaceous-Paleogene sedimentary and tectonic history and significantly different paleolatitudes, leading us to define two suspect terranes.

1. Golfo Terrane. - The Golfo Terrane forms the NE shore of the Golfo Dulce and the isthmus of the Osa Peninsula (Rincón - Boca del Sierpe). It is characterized by oceanic basalts and dolerites (over 95% of volume) and by stratigraphically overlying Campanian-Maastrichtian argillites.

Preliminary paleomagnetic data indicate equatorial Late Cretaceous paleolatitudes, which are significantly different from those known for Santa Elena, Nicoya and the Fila Costeña.

2. Burica Terrane. - The Burica Terrane forms the SW shore and the central high of the Burica Peninsula and is characterized by oceanic basalts, dolerites and hypabyssal rocks stratigraphically overlain by late Paleocene-middle Eocene pelagic and reddeposited shallow water sediments. Very proximal shallow carbonate debris flows in the central part suggest a near carbonate platform, whereas dominantly pelagic and turbiditic lithologies in coastal outcrops suggest a paleoslope adjacent to an oceanic seamount with water depths within the photic zone. Preliminary paleomagnetic data indicate a far more southerly Paleocene paleolatitude than for the rest of Costa Rica.

3. Caño Accretionary Complex. - The Caño Accretionary Complex forms the Caño Island and the pre-Neogene of the SW and central Osa Peninsula. The Complex is characterized by strongly deformed and low grade metamorphic turbidites and hemipelagic and pelagic sediments (over 95% of volume). In some places (San Pedrito-Maranco) 10-100 m sized blocks of oceanic basalts, dolerites and minor amounts of gabbros and acid differentiates occur in a pelagic sedimentary matrix. Central and outer Osa has no igneous basement. Some areas show deformed debris flows and turbidites of shallow water origin. Ages of pelagic and shallow water lithologies which occur as blocks or in turbidites range from Late Cretaceous to Oligocene. It is thought that the Complex is a result of Oligocene and post-Oligocene accretion in the Mid-American Trench. The different types of sedimentary melanges suggest offscraping of the sedimentary cover of the oceanic plate including both oceanic and trench-fill sediments. The latter consists of arc-derived turbidites which contain siltolites possibly derived from an outer high (Golfo Terrane?) forming the inner wall of the trench. Paleolatitudes, emplacement histories of the terranes and the accretionary history of Osa support current plate tectonic models suggesting a southwestern, Pacific origin and a NE-movement of the Caribbean plate between Campanian and Paleocene. The Burica Terrane, however, must have docked on the Caribbean plate in post-Paleocene times, after the formation of the Mid-American Trench.

# SEDIMENT SUBDUCTION AT THE LESSER ANTILLES CONVERGENT MARGIN.

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An interesting question to be addressed in geotectonics is how much sediment is accreted or subducted along convergent plate margins. Sediment subduction influences the geochemical balance of the Earth's mantle, and is a potentially important factor in the formation of island arc magmas. Sediment accretion is one of the long-term limiting factors of continental growth.

Sediment accretion versus sediment subduction at the plate interface Americas-Caribbean is investigated in a steady-state dynamic model. The model accounts for the geological evolution of the Eastern Caribbean borderlands since the Tithonian, and presumes that the "modern" Lesser Antilles subduction zone formed at about 48 mybp. Dynamic variables are: (1) growth rates of the accretionary wedge, (2) Rate of plate convergence, (3) Age of subducted crust through time, (4) Sedimentation rates on the subducting plate through time.

Size and age of the accretionary wedge can be approximated from the age of the Lesser Antilles island arc, and from reconstructed crustal profiles based on geophysical data. Convergence rates are constrained by plate reconstructions and the opening history of the Cayman Trough. A sedimentation rate profile on the oceanic crust east of the Lesser Antilles forearc is calculated from DSDP/ODP drillholes 27, 543 and 672, and is calibrated to finite thicknesses of the sedimentary column in front of the three sections studied across the subduction zone. Results and interpretations are as follows:

- (1) In front of the northern Lesser Antilles (Antigua/Anguilla) there is no or very little sediment subduction into the mantle.
- (2) The central segment (latitude of Dominica/Martinique) shows non-steady-state behaviour. Early terrigenous sedimentation and resulting rapid growth of the accretionary wedge is followed by hemipelagic sedimentation and slow wedge growth. This effect is probably caused by the arrival of the Tiburon Rise at the subduction zone. No estimations of sediment subduction are possible.
- (3) The southern segment (Grenada/Barbados) shows evidence for massive subduction of terrigenous sediments into the Earth's mantle.

# MUDSTONE MICROFABRICS, DEFORMATION MECHANISMS AND FLUIDS IN THE LESSER ANTILLES FOREARC.

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and  
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Deep ocean drilling (ODP Leg 110 and DSDP Leg 78A), extensive seismic reflection profiling and on-land structural studies, have made the Lesser Antilles Forearc one of the best constrained active accretionary wedges. Drilling at Site 671 achieved penetration of several active thrust faults, and the basal décollement zone of the accretionary wedge. We have examined in detail the microfabrics of tectonized muds in a discrete thrust at 128m, and in the basal décollement at 800m to 630m below sea floor. The thrust at 128m repeats at least 160m of stratigraphically defined rock column, constraining a total minimum displacement in the order of 600m. The fault rock comprises 6mm of mesoscopically foliated clays, bordered by undeformed wall rock. The 30m thick zone of sheared mudstones in the basal décollement at Site 871 contains a displacement in excess of 2000m.

High resolution backscattered electron images on the scanning electron microscope have been used to examine the microfabric of the forearc sediments. Clays and clasts are pervasively aligned in the immediate hangingwall to the 128m thrust. Microfabric intensity decreases upwards and the sediment is undeformed more than 6mm away from the thrust. In contrast the mudstones of Miocene age in the décollement zone have randomly aligned clays and clasts despite the evidence for significant strains from observed fold structures and balanced section inferences.

Deformation at the 128m thrust and in the basal décollement probably occurred by different mechanisms. One caused grain alignment, and one allowed accommodation of strain without grain alignment. Both are likely to be forms of particulate flow, but with contrasting grain interactions controlled by the fluid environment. The lack of grain alignment in the décollement was probably promoted by high pore fluid pressures and a cation-rich fluid which prevented development of weak clay-clay bonds by cation adsorption on clay surfaces. At higher levels, the 128m thrust for instance, such fluids may have been lost to the surface, and grain interactions were more dominant.

# CONTRIBUTION OF PALEOMAGNETISM IN THE RELATIONS BETWEEN THE PIEMONTEAN AND INTERNAL NAPES: SYNTHESIS AND NEW DATA.

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The east displacement of the Caribbean plate is occurring between the two Americas by large transcurrent zones, dextral and sinistral respectively to its south and north boundaries. This particular setting explains the 90° of clockwise rotations shown by the paleomagnetic vectors of the Venezuelan Caribbean Chain. With the end to define the relations between the piemontin and internal nappes of the Caribbean Chain, a study was realized in 1988, 100 km to the south of Caracas in the Guárico and Cojades States. Of the 21 sites perforated, 2 were in the internal nappe of Villa de Cura (to the north), 10 in the piemontin nappe and 9 in the autochthonous foreland (to the south).

- In agreement with the others paleomagnetic data, the Villa de Cura nappe gives evidence for 90° of clockwise rotation.
- The piemontin nappe do not show general rotation.
- The results about the foreland indicate a north-south orientation of the paleomagnetic vectors. They are according to the autochthonous character and to paleomagnetic declinations of the south-american craton.
- Nevertheless, the general north-south orientation of the paleomagnetic vectors can be deviated near the Guárico and Guaitoco faults (dextral faults).

These results, associated to the field data, confirm that the Villa de Cura nappe was a north-south oriented insular paleoarc, in agreement with the models of the Caribbean geodynamic evolution proposed by different authors (Pindell and Dewey (1982), Stephan (1982), Beck (1986)). On the contrary, the piemontin nappe did not rotate and has moved with an orientation similar to its original position. A possible flow of the piemontin unity could explain the declinations perpendicular to the front of this nappe, on which superposes the Guárico fault effect. Finally, the autochthonous oligo-miocene sandstones, to the south of the piemontin nappe, do not show rotations excepted clockwise near the Guárico and Guaitoco dextral faults.

# THE ESPINO GRABEN COMPLEX AND THE SOUTH LLANOS LINEAMENT: GRAVITY AND MAGNETIC ANOMALIES OVER A MAJOR UNEXPOSED RIFT ZONE AND MEGASHEAR IN NORTHERN SOUTH AMERICA

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Three Mesozoic graben complexes have been identified in northern South America: Takutu in Guyana and Brazil (Crawford and others, 1985); Maracaibo (Burke, 1976) in western Venezuela; and the unexposed Espino (Smith and others, 1984) in eastern Venezuela. Similarities among them are that they are about 30-60 km wide, 4-5 km deep, several 100 km long, and contain red sediments and volcanics.

On the basis of magnetic anomalies it is proposed that the southern margin of the Espino Graben complex - the South Llanos lineament - extends for about 800 km in Venezuela and into Colombia. Interpretation of these anomalies indicates that the South Llanos lineament is a zone characterized by a series of normal faults. South of the Espino drill-hole the fault throw is down to the north, and north of the hole down to the south. The graben zone is over 100 km wide.

Analyses of gravity anomalies indicate that there is "high-density crust" just north of the Espino drill-hole. These data suggest that this portion of the crust underlying the Eastern Venezuela Basin could be related to the Mesozoic rifting event. Gravity-high closures to the southwest of the drill hole may be related to volcanics, similar to those reported in the Espino well.

The geophysical and drill-hole data place constraints on the pattern of the Mesozoic breakup of Pangea, the northern margin of the South American craton, and the development of the Caribbean plate.

# LES BASSES TERRASSES CORALLIENNES DE LA GUADELOUPE : IMPLICATIONS NEOTECTONIQUES.

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POINTE-A-PITRE (GUADELOUPE) CEDEX

L'étude des terrasses émiennes (Inter Riss - Würn) sur les îles calcaires de l'archipel guadeloupéen permet de préciser l'histoire récente postérieure à 100.000 ans B.P. de ce secteur de l'Arc des Petites Antilles.

BATTISTINI et al (1986) ont déjà proposé pour ces récifs quaternaires émergés un âge "émien" à partir de critères morphologiques et de datations radiométriques.

L'analyse radiométrique des terrasses successives situées à l'extrémité Est de la GUADELOUPE (Grande-Terre) en utilisant <sup>238</sup>U et <sup>232</sup>U comme traceurs (BERNAT), suggère des périodes de haut niveau marin associées à des développements récifaux d'âge compris entre 100.000 et 160.000 ans B.P.

Aucune étude précise sur la déformation de ces niveaux de terrasses n'a été réalisée à ce jour. Ils constituent le marqueur stratigraphique daté le plus récent (= 100.000 ans B.P.). Leur position haute émergée, (+ 8 m pour celles de la Pointe-des-Châteaux) associée à des failles normales à rejet métrique indique un état de contrainte en distension avec des déformations en extension radiale.

Ces niveaux fournissent des déformations cassantes les plus récentes et l'âge des derniers rejets des failles. C'est ici un élément important pour l'évaluation de l'aléa sismique.

La fracturation E-W affectant les terrasses est comparable en tout point à celle de MARIE-GALANTE au Sud et à la DESIRADE à l'Est. L'analyse microtectonique pour ces secteurs montre que l'archipel est soumis actuellement et depuis le Pliocène supérieur à une extension radiale. À MARIE-GALANTE, la faille majeure affecte les basses terrasses émiennes et les niveaux de plage supérieurs avec un rejet d'environ 100 m. Les terrasses et les niveaux de plage sont affectés par des accidents normaux E-W. Leur étude fait apparaître une extension radiale identique à celle de la GRANDE-TERRE.

La Basse Terrasse de la DESIRADE est en position haute (+ 10 m à + 4 m). Elle est surmontée par des plages émergées à galets. Des accidents récents E-W découpent et verticalisent aussi bien les plages supérieures à galets que la terrasse émiennne ou les coraux et les brèches coralliennes.

L'interaction des mouvements tectoniques et des oscillations marines sont responsables de l'édification des complexes de terrasses récifales. On a ainsi la possibilité d'estimer avec une bonne approximation la vitesse moyenne de ces déformations. Ces dernières n'ont rien de comparable avec les terrasses marines des Grandes Antilles (CUBA, HAÏTI, JAMAÏQUE) qui culminent à plusieurs centaines de mètres au-dessus du niveau de la mer.

## NOUVELLES DONNÉES STRUCTURALES SUR L'ÎLE DE ST CROIX ET DE SON ENVIRONNEMENT.

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POINTE-A-PITRE (GUADELOUPE) CEDEX

L'Arc des Petites Antilles se termine par la plateforme d'ANGUILLA - ST MARTIN - SOMBRERO. Le passage d'ANEGADA marque le passage aux Grandes Antilles. Il se prolonge par le bassin des Îles Vierges entre VIEQUES et ST CROIX. L'île de ST CROIX occupe une position excentrée dans ce contexte. La transition Grandes-Antilles - Petites Antilles est marquée par une évolution spatio-temporelle du magmatisme liée à une tectonique polyphasée : l'une d'âge postérieur au Sénonien-Paléogène, l'autre évoluant au Mio-Pliocène.

Les travaux de (BONNETON et BECK, 1987) ont permis de mettre en évidence deux sites fossilifères à Rudistes du Sénonien supérieur (Campanien sup. à Maestrichien) à ISAAC POINT, en plus de ceux mentionnés par WHETTEN (1966) et ANDREIFF et al (1986).

On a donc un âge Sénonien pour toute la moitié orientale de l'île et la possibilité d'un âge Cénomaniens dans ce secteur (SPEED 1979) est rejeté. Le secteur NW de l'île (Hammes-Bluff, Springfield, St Georges) a révélé des localités très riches en microfaunes. Ces niveaux sont apparemment en continuité avec la partie Est de l'île avec un passage à Judith Fancy. D'un point de vue structural on assiste à un basculement généralisé des axes de plis synchistaux tant à l'Ouest qu'à l'Est. Dans la partie occidentale on a de grands cisaillements plats qui ne peuvent en aucun cas être interprétés comme des charriages. Les études microtectoniques montrent plutôt un régime en extension radiale E-W. de part et d'autre du graben central. À l'Est de l'île la tectonique polyphasée y est plus nette. Un régime en extension donne des failles normales associées à des décrochements en compression.

Les séries du Crétacé supérieur-Paléogène tectonisées de ST CROIX ont joué en compression (N-S à vergence Nord) comme à TORTOLA mais l'édifice a également fonctionné en distension. L'âge de certains dykes de ST CROIX (H. BELLON) serait Eocène supérieur, ce qui placerait une première phase tectonique distensive entre l'Eocène moyen et la base de l'Oligocène.

Plus à l'Est à ST MARTIN. Les accidents E-W sont localement décrochants dextres avec des conjugués à SW-NE. Le Miocène supérieur est affecté par une extension radiale pure SW-NE associée à ces décrochements. De part et d'autre du fossé d'ANEGADA on a des séries paléogènes très peu déformées (ST MARTIN, ANGUILLA, CULEBRA). Des séries du Crétacé supérieur Paléogène très tectonisées témoins d'un édifice soumis à une tectonique polyphasée : un régime compressif N-S à SW-NE associé à un régime distensif débutant à l'Eocène moyen et se poursuivant jusqu'au Mio-Pliocène (ST CROIX et TORTOLA). Conséquences des coulissements E-W déjà signalés à ST THOMAS.

# EL MEZCLAGE OFIOLÍTICO DE HOLGUÍN (CUBA NORORIENTAL) Y SU SIGNIFICADO TECTÓNICO

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El área investigada forma parte del cinturón ofiolítico de Cuba septentrional. Aquí, aflora el contacto entre el margen continental mesozoico norteamericano, representado por la Plataforma de Bahamas y la zona de mezcla ofiolítica que actualmente se encuentra en posición alta, sobrecoorrida sobre el margen continental. El término de "mezcla" se utiliza según el concepto de Hau - (1966).

Entre los componentes constitutivos principales del mezcla, se reconocen fragmentos de tres unidades paleotónicas del mesozoico tardío: banco carbonatado del margen continental y de su basamento silíceo metamorfozado, fragmentos de una asociación ofiolítica completa del fondo oceánico incluyendo sus bloques metamorfozados, y fragmentos de un arco volcánico maduro.

La edad de la formación más joven, constituyente del mezcla, es Eoceno temprano. La cobertura postorogénica se caracteriza por sedimentos terrígenos del Paleógeno tardío, mientras el Neógeno se destaca por el predominio de rocas carbonatadas.

Dentro del mezcla se diferencian mantos de corrientes con estructura interna fuertemente ondulada, dirigidos con pocas variaciones hacia el Norte. El manto inferior contacta directamente con el mezcla continental, mientras los superiores lo sobreyacen tectónicamente.

Las características del mezcla indican un desarrollo continuo de la colisión, hasta el cierre gradual de la cuenca suboceánica ubicada entre el margen continental y el arco volcánico. Los momentos culminantes del desarrollo son: cese del vulcanismo en el Campaniano Superior, formación de olistostromas en el Paleoceno y la conclusión del avance de los mantos de corrientes en el Eoceno Medio.

El análisis formacional y facial de las rocas componentes del mezcla, permite la reconstrucción esquemática de la situación paleogeográfica anterior a la colisión, del Cretácico tardío (de Norte a Sur): margen continental pasivo fallado, subcuencas oceánicas remanentes parcialmente consumidas, zona de subducción con buzamiento hacia el Sur, cuenca de antearco, arco volcánico.

## MANIFESTACIONES DEL DIAPIRISMO ARCILLOSO EN EL MARGEN COLOMBIANO DEL CARIBE

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## RESUMEN.

Utilizando cañones de agua y ecosondas de 3,5 KHz, se tomaron nueve perfiles sísmicos que cubren aproximadamente 1.500 km lineales de información. Se observan variadas manifestaciones del diapirismo arcilloso, que se han clasificado en abombamientos, domos, volcanes, pliegues y plumas diapíricas. Domos y pliegues se encuentran especialmente al sur de la latitud 10°30', y corresponden a movimientos de masas de gran extensión, alcanzado hasta más de 2 s.t.d. de espesor; hecho este que consideramos como el modificador principal de la morfología del margen de este sector. Los volcanes, generalmente situados en la cumbre de domos y pliegues representan la expresión actual del diapirismo a través de los cuales se expulsan tanto arcilla, como fluidos (agua y metano). Las plumas, a diferencia de las otras manifestaciones, en general, no deforman las capas intrudidas y su presencia está limitada a la zona de plataforma, hacia el norte de la latitud mencionada, definiendo así dos áreas claramente diferenciables, tanto desde el punto de vista morfológico como sedimentológico y estructural.

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# GEOLOGICAL SETTING OF SOME POLYMETALLIC MASSIVE SULFIDE OCCURRENCES IN THE MEDIAN BELT, CENTRAL DOMINICAN REPUBLIC

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The Median Belt, 185 km in length, of mainly metamorphic and mafic volcanic rocks of Cretaceous and possible pre-Cretaceous age, flanks the east and north edge of the Cordillera Central in the Dominican Republic, and contains several polymetallic massive sulfide occurrences. Some of these occurrences are being evaluated by Falconbridge Dominicana, Falconbridge Ltd and Recursos del Caribe S.A. Three occurrences have been selected to show the diverse characteristics and distinct geological environments.

The Sabana Potrero copper prospect is hosted by mafic volcanic rocks (mainly pillow lavas) of the Peralvillo Formation of Late Cretaceous age, at the northeast contact of the Median Belt peridotite. It consists of lenses of fine-grained copper rich massive pyrite which are structurally overlain by a quartz-sulfide stockwork and complexly intruded by mafic rocks.

The Cerro de Maimon deposit contains 2.9 million metric tons of sulfide ore grading 4.06% Cu, 0.07% Pb, 1.83% Zn, 44.9gm Ag/t, 0.47gm Au/t. It is associated with Early or pre-Cretaceous felsic meta-volcanic rocks of the Maimon Formation near the contact with rocks of the Peralvillo Formation. The massive sulfide body is conformable with the enclosing rocks and structurally underlain by an extensive zone of pyritic quartz-sericite rock.

The Amina Formation considered to be the stratigraphic equivalent of the Maimon Formation hosts the El Anon massive sulfide prospect in the northwestern Dominican Republic. The copper-zinc rich massive sulfides are localized within a narrow, four km long belt of pyritic quartz-sericite (chlorite) schists, and fine felsic meta-volcaniclastic rocks. The adjacent rocks are principally laminated and banded mafic meta-volcaniclastic rocks with thin to thick felsic interlayers.

The stratigraphic settings, distribution and types of alteration and mineralization, and metal zoning support a volcanic exhalative origin for the sulfide occurrences and highlights the potential for a diversity of deposit types in a variety of volcanic-tectonic environments.

# TECTONIC ESCAPE IN THE EVOLUTION OF THE CARIBBEAN

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In tectonic escape, material is displaced laterally from a region of high stress to a region of lower stress. Areas of high stress are usually associated with convergent plate margins and continental collision zones, and areas of low stress state generally involve oceanic free faces. Escape has lately been shown to be a significant factor in the evolution of major orogenic systems, as well as an important control in modifying local geologic relationships. Caribbean plate boundary zones are currently being modified by tectonic escape, and escape has been important at various stages of Caribbean plate evolution.

The best known area of active escape occurs in Colombia and Venezuela and involves the northward motion of the Maracaibo block and related fragments as a result of the collision of Panama with northwestern South America. The net regional displacement due to escape, as well as differential motion between individual fragments, is accommodated by a complex system of strike-slip faults. Displacements on the larger strike-slip faults, for example the Santa Marta and Bocono faults, range to approximately 100 km. The free face to this system lies in the Venezuelan Basin, where it is associated with a broad thrust belt related to the net convergence between the Maracaibo block and the Caribbean plate. Where the southern strike-slip margin of the Caribbean and the escape system meet, South American material carried northward is being sliced off and redistributed to the east along the plate boundary zone.

Tectonic escape appears also to be occurring in the northeastern Caribbean, to the east of Puerto Rico. This area, including the eastern Greater Antilles and northern end of the Lesser Antilles accretionary prism, is in transit from a confined state to an unconfined state as it passes the Bahamas Platform. To the west of this area secondary structures reflect east-west trending strike-slip motion. Past the transition, however, a northeast-southwest trending extensional strike-slip system accommodates northward escape toward a free face in the Atlantic.

A more complex example of Caribbean tectonic escape is discernable in the western tip of Cuba, and is related to the Paleogene collision between the Caribbean plate and the Bahamas platform. Along the northernmost part of the plate boundary, between Cuba and Florida, suitable conditions developed for tectonic escape out of the collision zone and into the Gulf of Mexico. A group of strike-slip faults in western Cuba may represent a part of the escape system.

# Modeling sediment compactional response to lateral stress in the Barbados Ridge Complex

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The impact of lateral stress on mechanical diagenesis of marine sediments was studied using Deep Sea Drilling Project (DSDP) and Ocean Drilling Project (ODP) sediment physical property data.

A statistical evaluation of the Deep Sea Drilling Project (DSDP) sedimentological and mass physical property database (Legs 1-96) yielded functions for the depth dependent compactional behavior of a set of standard sediment types. These "typecurves" are well constrained for mainly pelitic and psammitic sediments of moderate carbonate content. They are employed as a reference tool for the quantification of tectonically induced consolidation in the Barbados Ridge accretionary wedge.

Based on the developed typecurves and sediment physical property data from DSDP- and ODP legs 78A and 110 (Barbados Ridge) as well, a simple palaeokinetic reconstruction procedure was employed to determine porosity changes during accretion. Palaeostatically removing the compactional effects of burial diagenesis caused by imbricate stacking of wedge slices, a synthetic preaccretion porosity vs. depth profile could be modelled, which bears strong resemblance to characteristic profiles from 2 reference drill holes in front of the accretionary wedge (sites 543 and 672).

Comparison of synthetic and reference profiles reveals a lithologically controlled exponential relationship between depth and porosity divergence. Reevaluation of the reconstruction procedure in terms of involved stresses yielded a semiquantitative estimate of the relative and absolute impact of the lateral stress component on sediment consolidation in this part of the convergent plate margin.

This semiquantitative definition of compactional response to the lateral stress component provides an important constraint for further modeling of deformational behavior of accreted sediments.

# PRE-HOLOCENE SURFACE CONTROL ON HOLOCENE BANK BARRIER REEF DEVELOPMENT, ST. CROIX, U.S. V.I.

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An E-W series of 16 cores drilled along 2.5 km of the reef crest parallel to shore shows the pre-Holocene surface (PHS) dips east (1m/km). In a N-S transect perpendicular to shore, 10 cores showed the PHS dips more gently to the north except at a depth of -8.5m MSL where a 4m bench occurs locally. In the context of Holocene sea level dynamics and consequences, both the easterly dipping shelf and the bench influenced the timing, location, and the development style of the structural facies forming the reef. Fourteen radiocarbon dates show the reef first reached sea level 1455 YBP, near the center of the reef, not reaching sea level to the west until the present, and to the east from 120 to 803 YBP. The large structural elements in the reef cores first appeared 6135 YBP and form the thickest patch reef facies in the center of the reef, whereas rubble and sand increased to both the east and west. The seaward position of the reef is locally determined by the bench. Facies distribution indicates the reef developed as a series of patch reefs aligned parallel to the shore that coalesced into a continuous barrier. Patch reefs reaching sea level prograded seaward.

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Las Epocas Metalogénicas (EM) que fueron origen a los principales grupos formacionales de yacimientos minerales de Cuba se determinan en vinculación histórico-geológica durante el proceso de formación de la isla. Para esto se acepta la formación del Caribe a partir del freccionamiento del Pangea y el desarrollo de una riftogénesis durante el Mesozoico Temprano con la formación sincrónica de los Márgenes Continentales (MC) y la Corteza Oceánica (CO), durante el Jurásico-Cretácico Temprano, seguida con el régimen de Arco Insular (AI) (en dos edades) K y Pg y la disposición del complejo de cobertura a partir del Oligoceno.

Con el régimen riftogénico se desarrolla la primera EM durante el Jurásico Tardío y Cretácico Inferior con la deposición de los yacimientos sulfurosos en el MC pasivo y probablemente la formación de las segregaciones de cromitas en la base de las ofiolitas. Con el complejo del lecho oceánico se asocia los yacimientos de Cu.

Una segunda EM se vincula al régimen de AI Cretácico donde se formaron yacimientos de Cu, Cu-Zn y Pb-Zn. Al final de este período y en relación con las intrusiones de granitoides se formaron yacimientos de Fe-skarn, Cu-Mo y Au.

Durante el Paleógeno relacionado con el AI de esta edad, se desarrollaron los yacimientos de Cu, Pb-Zn y manganeso vinculado al complejo sedimentario. Durante el Eoceno Medio vinculados a la penetración de las intrusiones de granitoides, se formaron yacimientos de Fe-skarn, Cu y Cu-Mo. Como indicaciones de una EM, todavía poco fundamentado, con poca importancia regional, aparecen las mineralizaciones sulfurosas superpuestas en el Cenozoico.

La EM más reciente se relaciona con los yacimientos surgidos a partir de la acción supergénica sobre los complejos rocosos formados, dando lugar a la formación de yacimientos de Ni-Co-Fe, Fe y Al.

#### GEOMETRY AND TECTONIC REGIME ALONG A MAJOR STRIKE-SLIP FAULT: THE NORTHERN CARIBBEAN TRANSCURRENT PLATE BOUNDARY FROM CUBA TO HISPANIOLA, GREATER ANTILLES (73°W to 77°W)

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Marine geophysical surveys using *Seabeam*, single-channel seismic reflection, gravimetric and magnetic measurements were undertaken along the Northern Caribbean transcurrent plate boundary during the SEACARIB II cruise (R/V Jean-Charcot, 16/11-23/12/1987).

One of the main goals was to explore a poorly-known segment of this plate boundary, located from Cuba to Hispaniola (73°W to 77°W). The collected data allow to better define the geometry and the tectonic regime of this mainly strike-slip area. They support the following results:

##### 1. concerning the tectonic regime along the plate boundary:

a. the eastern part of the Oriente Deep and the Santiago promontory are characterized by an active compressional tectonics. We call therefore this area the "Santiago Deformed Belt" extending from 76°40'W to 73°50'W with an east-west general trend. This deformed belt can be longitudinally divided in three main segments, each one characterized by a particular tectonic style. Its structuration can be related to a transpressional mechanism;

b. in the Windward Passage, the Saint Nicolas Basin is a rectangular depression bounded to the south and to the north by normal east-west trending faults. We demonstrate that it cannot be interpreted as an active pull apart basin, as done previously.

##### 2. concerning the geometry of the plate boundary:

a. along the southern Cuban margin, the Oriente fault displays a discontinuous trace. It is composed of at least three main *en relais* segment;

b. through the Windward Passage this major fault cannot be connected to the subduction front of the Atlantic oceanic lithosphere under Puerto Rico and Hispaniola. On the contrary, it continues eastward on land, into the Cibao Valley in Hispaniola. Thus, we have for the first time the structural evidence of this connection, as it has been suspected from seismologic data. The Northern Caribbean plate boundary displays therefore a strike-slip/subduction association. Such a structural arrangement is similar to other regions of the world such as Sumatra, Andaman, New-Zealand and Philippines.

Our data strongly suggest that a tectonic and kinematic reorganisation recently occurred in this area. In comparison with the geological events recorded on land in the Northern Caribbean domain, we can propose a *plio-quaternary* age for this reorganisation.

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WE RECOGNIZED AT PRESENT, BELOW THE LATE CENOZOIC CONTINENTAL VOLCANIC ROCKS AND MARINE SEDIMENTS, A COMPLEX FOLDED AND FOLIATED ASSEMBLAGE OF LIMESTONE, SHALE, SLATE, CUARCITE GREYWACKE, TUFF, ANDESITE, DIABASE, SERPENTINE AND OTHER ULTRABASIC ROCKS WHICH CAN BE INTERPRETED LIKE FRAGMENTS OF A LATE MESOZOIC AND EARLY CENOZOIC VOLCANIC ISLAND ARCS AND OCEANIC CRUST.

IN BOTH CRUSTAL PLAINS, SEVERAL WELLS HAVE BEEN DRILLED, SOME OF THEM CONFIRM THE OCEANIC NATURE OF THE BASEMENT, THE CRUSTAL THICKNESS HAVE BEEN ESTIMATED FROM 25 TO 40 KM, AND SEISMIC VELOCITIES INDICATE AN OCEANIC TO INTERMEDIATE CRUST. THE CHORTIS BLOCK AT PRESENT IS MAINLY A COMPOSITE TERRANE - SIMILAR OF THOSE OF THE SIERRA MADRE DEL SUR IN MEXICO, THE GREATER ANTILLAS, COSTA RICA AND PANAMA, PROBABLY FRAGMENTS OF A LATE MESOZOIC VOLCANIC-ISLAND ARC AND OCEANIC CRUST - SUPRATERRANE ORIGINATE IN THE PANTHALASSA.

IT WAS FOLDED AND INTRUDED BY GRANITE PLUTONS DURING LATE CRETACEOUS AND EARLY CENOZOIC SIMILAR TO THOSE OF THE AMERICAN THRUST BELT FORMED DURING THE MAJOR PACIFIC ACCRETIONS. THIS OCEANIC MESOZOIC BASEMENT WAS OVERLAPED BY ISLAND ARC ASSEMBLAGES LATE CENOZOIC IN THE PRESENT PACIFIC RANGES, CONTINENTAL VOLCANIC IGIMBRITES IN THE CENTRAL CORDILLERA AND DELTAIC WEDGE AND CARBONATES IN THE ATLANTIC PLAIN AND SHELF. THE ACTIVE TECTONIC HAVE BEEN BROKEN THE AREA ORIGINATING THE CHORTIS-NICARAGUA ACTIVE PLATE.

#### THE IMPORTANCE OF THE 1988 TREMORS, JAMAICA: A DISASTER MANAGEMENT PERSPECTIVE

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During 1988 three tremors of magnitude greater than 4.0 affected Jamaica. In addition, many smaller tremors were felt and reported by the public. The three larger shocks were the heaviest felt since the 1957 earthquake (MMI VIII - IX) and provided the opportunity to gather data invaluable to pre-disaster planning and post-disaster response.

Unfortunately, the seismological value of these small earthquakes was lessened by the lack of adequate monitoring and recording equipment at the Seismic Research Unit. They did, however, produce other "positive" results including heightened public awareness of the earthquake hazard and the opportunity for the Office of Disaster Preparedness to assess public reaction and thus indirectly, the effectiveness of its public awareness programme.

This paper discusses the importance of the data gathered and the implications of the lost seismological data.

# AGE AND STRATIGRAPHIC STATUS OF THE PALMISTE FORMATION, TRINIDAD, WEST INDIES.

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The Palmiste Formation has appeared as a stratigraphic unit in publications and internal company reports since 1968, but in the absence of its formal definition confusion exists concerning its age, stratigraphic status, criteria for its recognition and limits of its development.

Onshore, the Palmiste Formation is represented by the Palmiste Clay Member of Kugler (1959) which is developed along the Atlantic coast of the island between Radix Point and Guayaguayare Bay and has a maximum apparent stratigraphic thickness of more than 1,000 feet. It is separated unconformably from the underlying Mayaro Formation and overlying Quaternary deposits from which it is readily distinguished lithologically and paleontologically. Between 1966-1968, diagnostic planktic foraminiferal faunas of post-Middle Miocene age were recognized for the first time in Trinidad in samples recovered from the Palmiste Clay and an Early Pliocene *Globorotalia margaritae* Zone age is assigned to the unit on the presence of the zonal marker.

The beds of the Palmiste Formation dip 5° - 35° south beneath Guayaguayare Bay and east to south-east beneath the Atlantic Shelf off Mayaro Bay where the formation is identified with a predominantly clay/shale interval encountered in well Palmiste-2. The interval exceeds 3,000 feet in apparent stratigraphic thickness and can be related to a characteristic seismic stratigraphic sequence observed on seismic data coverage in the area. The offshore unit appears to be restricted between the offshore extensions of the Southern Range and the Naparima-Nariva Thrust Belt, and its eastern limits appear to be fault bounded by a major N-S normal fault which exhibits some component of left-lateral slip. The sequence is assigned an Early Pliocene to possibly Late Pliocene age on planktic foraminifera.

So far correlation with the Late Pliocene Palmiste Formation of Leonard (1983) is not evident. The onshore sequence exhibits onlap westwards and the offshore sequence exhibits onlap relationships along its northern and southern boundaries. From these and other relationships, the Palmiste Formation appears to have been deposited in an areally restricted sub-basin formed as a result of the onset of uplift in the Galeota area of the Southern Range during the Pliocene. More recent tectonic movements emanating southwards from the Naparima-Nariva Thrust Belt have uplifted the offshore Palmiste Anticline and the Palmiste Formation may have been locally removed by erosion. Uplift of the coastal area has resulted in extensive removal of the onshore sequence.

# TECTONIC STYLE AND DEEP CRUSTAL STRUCTURE OF THE EASTERN CORDILLERA (COLOMBIA) FROM A BALANCED CROSS SECTION

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An E-W transect across the Eastern Cordillera from Yopal in the Llanos Province to Puerto Berrio in the Middle Magdalena Valley has been built using both subsurface and field data. It resulted in a balanced cross section well constrained in Mesozoic and Cenozoic series. The tectonic style in these levels is mostly controlled by low angle thrusting and decollement in the Cretaceous levels. The Cordillera is an asymmetrical thrust belt with east-verging faults along most of the transect. West verging structures are restricted to a 50 km wide belt near the eastern border of the Cordillera.

The shortening, estimated through the restoration of the Cretaceous levels to their pre-Neogene state, amounts to 150 km.

An attempt to constrain the deep crustal structure was made through gravity modelling. The asymmetry of the Cordillera and its deep structure supports a westverging continental subduction.

# INTERPRETATION OF GRAVITY ANOMALIES, MASAYA CALDERA COMPLEX, NICARAGUA

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The Masaya caldera complex, Nicaragua, has been the site of at least two Plinian eruptions in the Quaternary and remains active today. We have interpreted gravity data collected during a regional gravity study by Williams (1972) in an effort to further delineate geologic structures associated with this major volcanic feature. A total of 217 gravity stations were occupied in the vicinity of Masaya caldera. These data were reduced to the complete Bouguer anomaly by Williams (1972). We contoured these data over an area of approximately 25 x 15 km, centered on the caldera, using a minimum curvature algorithm. Several large amplitude gravity anomalies are apparent on this map. These include a broad +35 mgal high on the NE side of Masaya caldera, and a locally steep gradient within the caldera, just NW of the active Santiago vent.

Upward continuation to 1500 m has the effect of isolating the broad positive gravity anomaly. The aspect of this large, positive gravity anomaly is like that of Masaya caldera itself: elongate approximately N60W, parallel to the strike of the Nicaragua Depression. Near surface, local anomalies were isolated by wavelength filtering. A high-pass, ramped filter was constructed such that anomalies at wavelengths longer than approximately 6 km are strongly attenuated. Of note is a negative anomaly, located immediately NW of the Santiago Crater. Although the true extent and amplitude of this anomaly cannot be determined from the data, its presence suggests mass deficiency, spatially associated with the active craters on the caldera floor.

We created a two-dimensional gravity model along a NW-striking traverse, bisecting the large positive anomaly. No surface geologic contacts or discontinuities are associated with the broad positive gravity anomaly and it is modeled as a completely buried anomalous mass. Regional faults, associated with the Nicaragua Depression, can be interpolated through Masaya caldera. Although there is no vertical displacement of rocks due to regional faults within the caldera, the presence of strong N60W oriented structures is suggested by the alignments of vents on the caldera floor and the distribution of soil geochemical anomalies within the caldera. These regional faults may affect gravity gradients, but their effect on the NW-striking profile is minimal. The key elements of the model are a high density contrast, 300 to 500 kg/m<sup>3</sup>, and the thin, plate-like geometry of the anomalous mass. This plate is 15 km long, approximately 0.75 - 1.0 km thick, and buried at a depth 0.1 - 0.6 km. A contact dipping away from the center of the anomalous mass is required. We believe this anomaly is likely of igneous origin. The geometry of the causative body suggests that it is either and igneous intrusion, possibly a laccolith or sill, or a series of lavas, which have accumulated to substantial thickness over a limited area. The presence and extent of this anomaly is indicative of the complex volcanic history of this caldera.

Williams, R.L., 1972, The geology of western Nicaragua: Tax improvement and natural resources inventory project, Final Technical Report, v. 4, Managua, Nicaragua.

# CARACTERÍSTICAS SISMOLOGICAS ASOCIADAS A LA ERUPCION PAROXISMAL DEL VOLCAN NEVADO DEL RUIZ - COLOMBIA

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## RESUMEN

Se analizan las principales características de los eventos sísmicos asociados al Volcán Nevado del Ruiz durante 1985 y 1986, como son la magnitud local, el parámetro b, energía liberada, tipo de sismicidad y su comportamiento en el tiempo y el espacio, el mecanismo focal, momento sísmico, tamaño de la ruptura y valor de los esfuerzos liberados.

Se propone la utilización de las fórmulas empíricas para la magnitud de  $M = 2.82 \log (+) - 246$  para los eventos de alta frecuencia (mayores o igual a 4 Hz), llamados tipo A y  $M = 2.82 \log(t) - 2.34$  para sismos de baja frecuencia (menores a 4 Hz), llamados tipo B, los cuales se ajustan mejor a los rangos de magnitud observados en el Nevado del Ruiz. Del análisis de las variaciones del parámetro "b" para los sismos Tipo A y Tipo B parecen estar correlacionados y muestran un incremento de sismos de baja frecuencia de relativa mayor magnitud cuando crece el número relativo de sismos de alta frecuencia de menor magnitud.

Por medio de la acumulación de sismos en el tiempo se establecen tres fases características en cada episodio de actividad volcánica que culmina con uno u otro evento volcánico de importancia. Se nota una disminución de la actividad sísmica y energía sísmica liberada que precede cada erupción. El análisis de estos resultados nos permiten suponer que la disminución en la liberación de la energía sísmica conlleva a un incremento en la energía de deformación del volcán antes de la erupción.

Aunque el estudio de los parámetros focales aún está desarrollándose, hemos logrado observar valores muy bajos del momento sísmico, del orden de  $10^{17}$  dinas x cm, radios promedios de ruptura de 0.4 km y valores supramente bajos de caída de esfuerzos ( $10^{-3}$  bares), que parecen aumentar en un orden de magnitud varios días antes de la erupción del 13 de noviembre de 1985.

# **PARTICULARIDADE GEOLOGO-GEOQUIMICAS DEL ARCO VOLCANICO PALEOGENO Y SU APLICACION EN EL PRONOSTICO METALOGENICO**

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En el Mapa de Anomalías Geoquímicas de Cuba a escala 1:500 000 se detectaron en la región de la Sierra Maestra 16 anomalías obtenidas por flujos de dispersión, aureolas secundarias de dispersión en los depósitos friables y por aureolas primarias. Estas anomalías están relacionadas con mineralización menífera de yacimientos conocidos, manifestaciones o puntos de mineralización.

Hemos asumido que la Sierra Maestra se divide en seis bloques neotectónicos, de oeste a este: Marea del Portillo, Inferno, Turquino, La Bayamesa, El Jobo y Gran Piedra. Estos bloques presentan un desplazamiento vertical de diferente magnitud, presentando por tanto diferente profundidad del corte de erosión.

El Bloque El Jobo es muy conocido pues en él se encuentra el yacimiento El Cobre, así como una serie de manifestaciones de interés. Los bloques Inferno y La Bayamesa presentan características similares en cuanto a la disposición de las anomalías en forma de anillo siguiendo las estructuras circulares vulcano-plutónicas. En el bloque La Bayamesa la composición de las anomalías también es característica para la mineralización de Cobre-Polimetalico, y en la parte central de la estructura circular es típica para la mineralización cuprífera relacionada con el intrusivo Guama Sur-Bayamita. Entre estos dos bloques se encuentra el bloque Turquino que es el más elevado de toda la Sierra Maestra, y el menos prospectivo. El bloque Marea del Portillo, es el más occidental de la cordillera, el menos erosionado, y presenta anomalías geoquímicas que pudieran estar relacionadas con la manifestación Marea del Portillo conocida en ese lugar. Se indica una probable mineralización ciega en profundidad. El bloque Gran Piedra es el más oriental de la sierra, al este del cual aflora el intrusivo Daiquirí. Las anomalías que se manifiestan tienen las particularidades de la mineralización de cobre polimetálico; controlados por un sistema de fallas, que en ocasiones guardan relación con los yacimientos de Hierro de tipo skarn magnéticos.

# **CATALOGO DE LOS MOLUSCOS FOSILES DEL NEOGENO-CUATERNARIO DE CUBA.**

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Se presenta una versión resumida del catálogo de los moluscos fósiles del Neógeno-Cuaternario de Cuba, preparado sobre la base de las colecciones formadas durante años por el autor, así como por los fósiles colectados en los trabajos de levantamiento geológico realizados en el Instituto de Geología y Paleontología. Este constituye el primer aporte (descontando el trabajo de M. FERNANDEZ DE CASTRO de 1876 que nunca llegó a publicarse) que reúne información sobre la totalidad de la fauna estudiada, ya que existen muy pocos trabajos anteriores sobre la materia, mayormente desactualizados y que hacen referencia solo a algunas especies pero no a la totalidad de la fauna. Este trabajo incluye reseña histórica, bibliografía más importante, relación taxonómica de especies, subespecies y taxones supraespecíficos representados, con información resumida de autor, fecha de publicación original, de cada especie, subespecie, género o subgénero así como distribución geográfica y estratigráfica, sinónimo más importante e índice alfabético de especies y subespecies así como algún otro dato que consideremos de especial interés. La pobre preservación de los ejemplares colectados en los estratos del Neógeno cubano constituye una de las razones que explican la escasez de trabajos existentes sobre el tema.

La utilidad práctica de este catálogo es grande para su uso por geólogos y paleontólogos en la determinación rápida de edades de muchas muestras sin recurrir a estudio micropaleontológico. Por otra parte, la reunificación de datos dispersos en gran número de publicaciones, muchas veces antiguas e insusceptibles a la fundamentación del trabajo, principalmente, en el estudio de muestras colectadas dan a este aporte valor científico y teórico.

## **LA ERUPCION PAROXISMAL DEL VOLCAN NEVADO DEL RUIZ - COLOMBIA**

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## **RESUMEN**

Con base en la sistematización de la información geológica se presenta un cuadro general y actualizado del área volcánica conocida como el Parque Natural de los Nevados.

El Nevado del Ruiz es uno de los volcanes del Parque Natural de los Nevados construido en dos etapas: volcán moderno (hace 500.000 años) y volcán antiguo (desde hace un millón de años).

En base a resultados publicados y observaciones propias, se describe un esquema del proceso eruptivo del Nevado del Ruiz. El presente ciclo eruptivo muestra varias etapas de actividad que se definen según el carácter con que se han desarrollado los eventos volcánicos. Estas etapas son: etapa pre-eruptiva, etapa eruptiva preparoximal, erupción paroximal y etapa eruptiva post-paroximal.

La etapa eruptiva parece culminar el 22 de diciembre de 1984, fecha en que ocurrió una serie de temblores de tierra debajo del volcán que dan lugar al inicio de la etapa eruptiva preparoximal, la cual se prolonga hasta el 13 de noviembre de 1985, cuando se presentó la erupción paroximal que causó la muerte a cerca de 25.000 personas y pérdidas materiales avaluadas en miles de millones de pesos. A partir del 14 de noviembre de 1985, se inicia la etapa postparoximal, en la cual se han presentado varios máximos de actividad volcánica, en su mayoría acompañados por extensión de cenizas.

## **DESCRIPCION DE TRES NUEVOS TAXONES SUBESPECIFICOS DE MOLUSCOS DE LA ETAPA PLIOCENO-CUATERNARIO DE CUBA.**

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En el presente trabajo se ofrece la descripción de tres nuevas formas de moluscos fósiles del Plioceno-Cuaternario de Cuba, las cuales son importantes desde el punto de vista estratigráfico, por lo que la publicación de dichos taxones permitirá su utilización en trabajos bioestratigráficos en nuestro país y en el área correspondiente a la Paleo-Provincia Faunal Malacológica Caribeña, establecida por WOODRING (1965; 1974) para el Mioceno y extendida más tarde por KOJUMDIEVA y A. de la TORRE (1980) y A. de la TORRE y KOJUMDIEVA (1985) hasta el Plioceno y existiendo probablemente desde el Eoceno Medio. Se hace referencia asimismo a otras especies asociadas o que corresponden a horizontes estratigráficos equivalentes. Las mismas, conjuntamente con los nuevos taxones descritos en este trabajo condicionarán a un mejor conocimiento de este lapso geológico en Cuba.

GEOLOGIA DE LA SIERRA DE NEYBA  
REPUBLICA DOMINICANA

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La Sierra de Neyba, localizada en la región suroeste de la República Dominicana, está constituida por rocas sedimentarias calcáreas, principalmente calizas terciarias, que se asocian con rocas volcánicas básicas emplazadas en el Eoceno Inferior.

Los flujos volcánicos, integrados fundamentalmente por basaltos, andesitas y piroclastos, datan de 52 millones de años atrás y están estrechamente relacionados con las calizas litográficas pedernalesas de la Formación Neyba, las que fueron depositadas en el Eoceno Medio.

La caliza litográfica de la Formación Plaisance, que es la base calcárea de la región, se concentra en la vertiente noroeste de la sierra, mientras que las calizas cristalinas y margosas de la Formación Sombrerito, que han sido posicionadas concordantemente sobre la Formación Neyba, afloran en la margen sur y en el extremo oriental del sistema montañoso de Neyba.

Las unidades clásticas de la región están representadas por las Formaciones Trinchera y Arroyo Blanco, del Oligoceno y Mioceno respectivamente, encontrándose que mientras Arroyo Blanco es rica en especies de macrofauna, las demás formaciones se caracterizan por la abundancia microfaunística.

La tectónica regional es extremadamente compleja, observándose cabalgamientos de calizas eocénicas sobre grandes mantos de calizas oligocénicas, lo que ha generado un extenso fracturamiento, que permite la rápida infiltración de las aguas meteoricas, las que posteriormente emergen a lo largo del principal plano de falla regional, constituyendo extraordinarios manantiales.

MINERALIZACIONES AURIFERAS EN LOMA NARDITA  
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RESUMEN

Las exploraciones geológicas, geoquímicas y geofísicas, así como las trincheras y perforaciones realizadas en una Reserva Fiscal de 6030,25 hectáreas mineras, localizada al noroeste de la ciudad capital de la República Dominicana, han permitido detectar la presencia de importantes concentraciones auríferas dentro de múltiples vetas de cuarzo, que cortan las rocas volcánicas de la Formación Duarte.

Esta Formación Duarte, de edad precretácica, y constituida por esquistos verdes, andesitas afaníticas, andesitas porfíricas, tobas andesíticas y doleritas, ha sido considerada como la fuente de todo el oro aluvial que se mueve a lo largo de las corrientes fluviales que drenan la vertiente norte de la Cordillera Central.

El programa detallado de geoquímica de sedimentos fluviales, llevado a cabo en toda la Reserva Fiscal mediante el sistema de preconcentrados, determinó, rápidamente, que las principales mineralizaciones auríferas se concentraban en un área de aproximadamente 350 hectáreas mineras, la cual recibe el nombre de Loma Nardita.

La geoquímica de suelos, orientada hacia la determinación de oro, arsénico y antimonio en los suelos lateríticos del área, reflejó muy pobres resultados, ya que el oro solo se concentra en las vetas de cuarzo, por lo que las rocas y suelos se muestran estériles.

Perfiles electromagnéticos realizados con slingram, detectaron ejes de anomalías que coinciden con la presencia de importantes vetas de cuarzo. Resultados menos concluyentes fueron obtenidos con el programa de polarización inducida (I.P.).

Perforaciones posteriores permitieron confirmar, que algunas de las vetas de cuarzo aurífero registradas en Loma Nardita, continúan por debajo de los 70 metros de profundidad, aunque con valores de oro muy variables, entre cero y 1900 grs. por tonelada, por lo que el trabajo exploratorio debe proseguir en forma sistemática.

CENOZOIC SEDIMENTARY AND DEFORMATIONAL HISTORY OF THE  
CENTRAL CORDILLERA SEPTENTRIONAL, HISPANIOLA

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The transition from convergent to strike-slip tectonics along the northern Caribbean plate boundary is recorded in the Tertiary basins of the Greater Antilles. In Hispaniola, the main zone of Eocene-Recent sinistral displacement at the plate boundary has occurred in the Cordillera Septentrional. Detailed stratigraphic and structural mapping indicate that Paleocene to early Pliocene sedimentary rocks exposed within the central Cordillera Septentrional (500 km<sup>2</sup>) can be divided into three lithologically distinct stratigraphic units, each of which are punctuated by a deformational event causing crustal shortening.

The first stratigraphic unit is approximately 250 m-thick, late Paleocene to early Eocene in age, and consists predominantly of suspension deposited, deep marine clastic and carbonate rocks (Los Hidalgos Formation) interbedded with calcalkaline volcanic sills and flows (Palma Picada Formation). Termination of deposition and volcanism in early to middle Eocene time coincides with a major folding and uplift event, believed to have resulted from convergence of the Bahamas Platform and the arc related basins at the leading edge of the Caribbean plate.

The second stratigraphic unit is 4000 m-thick and consists of upper Eocene to lower Miocene conglomerates, sandstones, and shales (Altamira, Las Lavas, and La Toca Formations) deposited by submarine mass-flows within west-northwesterly striking, elongate basins. The composition of framework grains from coeval sandstones changes abruptly across a linear, 100-400 m-wide sinistral shear zone, suggesting that two distinct basins may have been juxtaposed by post-Oligocene faulting. The end of siliclastic deposition in both basins coincides with a gentle middle Miocene folding event believed to be related to strike-slip faulting.

The third stratigraphic unit is approximately 250 m-thick and consists of upper Miocene to lower Pliocene shallow marine carbonate rocks (Villa Trina Formation). Carbonate deposition ended in early Pliocene time as a result of a folding and uplift event associated with transpression along the Septentrional Fault Zone.

STRUCTURE AND ACTIVE TECTONISM OF THE INSULAR MARGIN  
OFF NORTHWESTERN HISPANIOLA

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The insular margin off northwestern Hispaniola is a tectonic accretionary wedge, as disclosed by GLORIA broad-range sidescan sonar images and single and multichannel seismic profiles. The data show that the margin is characterized by two principal structural/morphological styles. One style, displayed off northeastern Haiti, has a relatively gentle sea-floor slope (about 4°) that merges gradually into the flat floor of the Hispaniola Basin to the north. Structures associated with this style of margin are broad anticlines separated by thrust faults that dip southward toward Hispaniola, which is acting as a backstop. The anticlines are formed by active syndepositional folding beneath the floor of the basin and at the foot of the insular slope. Subsequently they are sheared off above a main decollement and are thrust beneath the older folds of the accretionary wedge that forms the insular slope. The morphology of this margin type is dominated by slope-parallel anticlinal ridges. A fold-controlled submarine canyon channels turbidity flows to the floor of the Hispaniola Basin, where a fan has formed. The other structural/morphological style occurs off northwestern Haiti and off northwesternmost Dominican Republic, and it is characterized by a much steeper insular slope (as much as 14°). In this type, the foot of the insular slope commonly forms an abrupt angle with the basin floor at a structural front. Internal structure of the insular slope appears to be chaotic in seismic profiles. Areas characterized by the two slope types are adjacent and must have been affected by the same movements and history of plate collision. The differences in structure and morphology may result from variations in dip of the main decollement. Although overall plate motion north of Hispaniola is undoubtedly dominated by transcurrent movement, the structure of the insular slope shows few effects of such motion. Rather, we attribute the insular slope structure observed in our studies to collision, and we assume that strike-slip motion must be taken up to the south. The Hispaniola Basin apparently has been a turbidite basin near the plate boundary for a considerable period, and variations in southward thickening of apparent turbidite layers in the basin may provide a partial history of plate interactions.

# OBLIQUE COLLISION BETWEEN THE SOUTHEASTERN BAHAMAS AND HISPANIOLA: PRELIMINARY SEAMARC II/SINGLE-CHANNEL SEISMIC REFLECTION RESULTS

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The shallow-water Silver and Navidad Banks of the southeastern-most Bahamas are obliquely colliding with northeastern Hispaniola along a transpressive segment of the broad, predominantly left-lateral Northern Caribbean Plate Boundary Zone. During June 1989 we plan to study this collision using a combination of SeaMARC II side-scan sonar and digitally recorded single-channel seismic reflection data, to be gathered aboard the R/V Moana Wave. Our study will focus on several major goals: 1) to determine the mode of accretion of the banks to the margin of Hispaniola, with particular emphasis on testing the hypothesis that the banks 'dock' with the overriding margin during an outward jump in the subduction zone, 2) to understand the structural response of the overriding (Hispaniola) plate to collision of the buoyant shallow-water banks, and 3) to determine the role that tectonic activity plays in explaining the small size and erosional margins of the isolated banks of the southeastern Bahamas, which contrast markedly with the large, progradational banks of the tectonically quiescent northeastern Bahamas. Specifically, we want to determine if the narrow, linear troughs that separate the southeastern banks are zones of active faulting associated with the collision. This talk will focus on the preliminary results of the cruise.

# RECONSTRUCTION OF THE HISPANIOLA-SOUTHEASTERN CUBA ISLAND ARC AND IMPLICATIONS FOR ITS CRETACEOUS TECTONIC EVOLUTION

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Northern Hispaniola and southeastern Cuba contain similar, if not identical, rock suites of Late Cretaceous to Early Eocene age which exist in both regions. It is suggested that these two areas separated along the Oriente transform between mid-Oligocene to Late Miocene time. This separation accounts for only 400km of the proposed 1000 km of left lateral displacement on the northern Caribbean boundary. Other Tertiary faults in northern and central Hispaniola helped accommodate the displacement: Camu (70km), Hispaniola (50km), Guacare (30km), a proposed fault buried in the Cibao Valley (40km), Septentrional (unknown, but probably less than 50km), San Juan - Los Pozos (unknown, but probably less than 15km). If the Tertiary displacements are restored, the Upper Cretaceous island arc can be reconstructed. This exercise reveals that the Upper Cretaceous arc was a broad composite terrane containing a suture zone. It is suggested that the Early Cretaceous arc was generated by a northward dipping subduction zone. Early arc volcanics were deposited on an oceanic seamount structure (Duarte Complex). This arc rifted and formed a back arc basin, which was closed by a Campanian collisional event that thrust the main arc with its sea mount basement over the remnant arc and caused a flip in the polarity of subduction. The Lower Cretaceous-Lower Tertiary of North-central Hispaniola and southeastern Cuba therefore represents an amalgam of Cretaceous to Lower Tertiary terranes (seamount, Lower to Mid Cretaceous magmatic arc, suture zone, all stitched together by an Upper Cretaceous magmatic arc and accompanied by the Upper Cretaceous forearc terrane). The present structural character of Hispaniola is dominated by Neogene sinistral strike and oblique slip faults which cut obliquely across the trend of the Cretaceous-Lower Tertiary arc.

# EXTENSION AND TECTONIC INVERSION OF AN INTRA-ARC HALF GRABEN: THE WAGWATER BELT, JAMAICA

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The Wagwater Belt, Jamaica, is a belt of Paleocene to Eocene conglomerates, turbiditic sandstones, gypsum and volcanic rocks which separates two areas of Upper Cretaceous island arc rocks. The belt is bordered by two major fault zones: the Wagwater Fault Zone (WWFZ) on the southwest and the Yallahs-Blue Mountain-Plantain Garden Fault Zone (YBPFZ) on the northeast. The rocks within the belt are themselves folded and faulted.

It is suggested that the belt is best modelled as a northeast dipping (relative to modern Jamaica) lithospheric listric normal fault system producing a crustal half graben. The WWFZ and YBPFZ are considered to be two synthetic imbricate listric faults within this major fault system. Such a model can successfully explain (a) the asymmetric distribution of sedimentary facies in the Wagwater Group sediments (b) the low grade metamorphism and 40 my (approx.) K-Ar overprint found in the rocks of the Blue Mountains.

The WWFZ and YBPFZ (and the parent zone) were reactivated (tectonically inverted, in recent jargon) by compressive stresses related to Jamaica's Miocene and later E-W sinistral transcurrent movements. This resulted in reverse motion on the bounding faults of the belt and caused folding and reverse faulting within the belt.

This two phase model for motion on the WWFZ may explain the apparent right lateral offset of the Jack's Hill Granodiorite from the Above Rocks Granodiorite. If extension were oblique on the WWFZ, then eastward oblique slip of the Jack's Hill body down the fault plane during extension, followed by reverse dip slip during reactivation would produce an finite southeasterly displacement. Making certain assumptions about the geometry of the WWFZ, this suggests crustal extension of 20 - 25km.

Other NW-SE trending faults in Jamaica were probably part of the Paleocene-Eocene system of crustal stretching, but, with the exception of the Newmarket-Montpelier Zone, displacement was not sufficient to develop a clastic sedimentary basin. Alternatively, some basins did form, but reverse motion on their bounding faults during Miocene inversion was not enough to expose them, and they remain buried.

# NEOGENE TECTONIC DISINTEGRATION OF A CARBONATE EOCENE-EARLY MIOCENE MEGABANK ALONG THE NORTHERN NICARAGUA RISE, CARIBBEAN SEA

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The Northern Nicaragua Rise (NNR) is comprised today of the eastern Honduras/Nicaragua and southern Jamaica carbonate shelves, and a series of relatively small detached carbonate banks (i.e., Pedro, Rosalind, Serranilla and Miskito Banks) separated from each other by intervening basins and seaways. Based on recent seismic surveys of, (1) Walton Basin, located between the Southern Jamaica Shelf and Pedro Bank, (2) seaways on the western side of the NNR (Hine and Hallock Muller, this volume), as well as (3) the middle of the NNR (Univ. of Texas data), we postulate that the present bank and basin configuration evolved from a once continuous mega bank that was present along the entire length of the NNR from Eocene through early Miocene times. In the mid/late Miocene, this mega bank progressively broke up into a series of smaller banks, basins and seaways, mainly as the result of tectonic movements related to the overall strike-slip displacement within the North American and Caribbean Plate Boundary Zone of the Cayman Trench. At the same time, the most eastern portion of the mega bank was uplifted and today forms most of central and south Jamaica. The NNR basins and seaways, because of their common north trending orientation, have been previously interpreted as Paleocene to Recent rifts, becoming progressively younger from Jamaica to Honduras.

Our new interpretation of the NNR general evolution is documented by the results of a recent seismic survey in Walton Basin. The sea floor and subsurface of Walton Basin is clearly dissected by numerous dip-slip and strike-slip faults into a series of faulted and folded blocks as well as horst and graben structures. Most of these tectonic features, currently buried, appear to be inactive; however some faults, displacing the surface sediments, exhibit recent movements. On a detailed bathymetric map of Walton Basin, a plateau, currently at 600 m of water depth and comprising one third of the basin floor, clearly appears in our seismic grid as a drowned shallow bank overlain by a wedge of periplatform sediment thinning westwards from the edge of the Jamaica shelf. Smaller banks within Walton Basin, covered today by an average 30 m of water, represent small portions of the former bank that remain with the photic zone due to their location on high standing (faulted or folded) blocks. Intermediate cases are also observed, where small banks compensated for subsidence for some time, but subsequently drowned. Similar features were documented by Hine and Hallock Muller in the western seaways. There, a major (mid-Miocene?) unconformity separates the present arrangement of small banks and seaways from a large underlying carbonate (Eocene-early Miocene?) bank, dissected by near-vertical faults and fault-controlled folds. Interpretation of Univ. of Texas seismic lines from the middle of the NNR suggests that Pedro and Rosalind Banks also were connected until the early Miocene by a continuous bank. According to our new interpretation, the opening of seaways and basins along the NNR after the early Miocene would have initiated the northwestern flow of the Caribbean Current through the NNR. This more western path for the Caribbean Current could explain the initiation of the loop current at that time in the Gulf of Mexico. Since the mid-Miocene, the Caribbean Current has greatly influenced the evolution of the NNR banks and basins.



## STRUCTURE AND SPREADING HISTORY OF THE CENTRAL CAYMAN TROUGH

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The data from this study area in the Central Cayman Trough was obtained from several sources and include GLORIA sidescan sonar images, single-channel seismic profiles, magnetic intensity profiles, and swath bathymetry. This valuable data set demonstrates that features common to rift-transform systems in the Atlantic Ocean are also found in the Cayman Trough. These include transverse ridges, ridge and salients, nodal basins, and a well-displayed transform fault zone.

The sidescan mosaic demonstrates that northerly oriented ridges and valleys generated by seafloor spreading are present not only on the Mid-Cayman Rise, but also that similar ridges on older crust east of the rise are partially buried by sediment. The images also show a series of easterly oriented ridges of oceanic crustal rock in the southern part of the trough that are east of and adjacent to the rift valley. The northerly oriented ridges appear to terminate against the easterly oriented ridges.

The combined data suggest that a major displacement resulting from a ridge jump is not apparent, but minor shifts of the spreading center appear to have occurred, particularly within the rift valley. At least one inactive spreading system can be identified within the valley. A small-displacement jump may account for the presence of a large elevated crustal block lying within the rift valley.

## PETROLOGIA DEL BASAMENTO IGNEO-METAMORFICO DEL NORESTE DE LA CUENCA DE BARINAS-APURE.

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En la región noreste de la Cuenca de Barinas-Apure varios pozos han penetrado rocas metamórficas y sedimentarias consideradas como basamento económico y atribuidas al Precámbrico y Paleozoico indistintamente. El estudio petrológico de la secuencia reconocida en informes y publicaciones de la Industria Petrolera Nacional de Venezuela como argillitas de la Formación Carrizal en los pozos Apure-1, -2 y -3 (perforados entre los años 1947 y 1948) que infrayace a la sección cretácica da por resultado que se trata de dos grupos de rocas metamórficas bien diferenciables.

En los pozos Apure-1 y Apure-2 se encuentra un conjunto de rocas polimetamórficas constituidas por brechas de falla, microbrechas, milonitas (protomilonitas, filonitas, blastomilonitas) y pseudotaquilitas. El efecto tectónico (milonítico), asociado a las fallas de Guafita Caño Limón y Apure, se acentúa a profundidad y afecta a rocas sedimentarias originales sobre las que ha actuado un bajo metamorfismo regional en las facies de los esquistos verdes. En el pozo Apure-1 a una profundidad de 2913 m (8828 pies) y asociada a brechas de falla se presenta una roca ígnea (andesita) en gruesas vetas e intercalada con los sedimentos originales, la cual ha sido profundamente alterada y sus componentes máficos marcadamente uralitizados, y metamorfozados conjuntamente con las rocas sedimentarias arriba descritas. Su origen se asocia a los conjuntos de rocas ígneas básicas desarrolladas en márgenes continentales activos (suite calco-alcalina).

El pozo Apure-3 exhibe rocas metasedimentarias (metalmolitas arcillosas y metareniscas) con moderado desarrollo de la foliación y escaso fracturamiento y plegamiento. La textura, fábrica y estructura de la roca sedimentaria original son aún claramente observables.

Las rocas metamórficas arriba descritas se pueden incluir todas dentro de una unidad litodémica que en este trabajo se denomina Esquistos de Apure, cuyo holoestratotipo se ubica en el pozo Apure-3.

Similarmen se establece correlación con los esquistos y gneiss de los pozos Agua-Linda-1, SZW-3 y Ticoporo-1, Rosalia-1, Capitanejo-1 (ubicados dentro de esta misma cuenca) cuyas edades se consideran Silúrico temprano (edades radiométricas sobre estas rocas con el método K/A, de tal manera que la faja orogénica paleocénica propuesta en la literatura en la región de los llanos occidentales se amplía al área del Edo. Apure hasta su límite con el precámbrico de Guayana (curso Río Arauca).

## COMPILATION MAPS OF THE ENERGY AND MINERAL RESOURCES OF THE DOMINICAN REPUBLIC

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Three maps at 1:200,000 and accompanying text have been prepared showing the location and basic information on all the known occurrences of metallic and non-metallic mineral and energy resources in the Dominican Republic.

Gold, with associated silver, is the most important mineral in terms of value and occurs as epithermal, vein and placer deposits. There are more than 100 known significant occurrences of placer gold.

Nickel laterite is the second most valuable mineable metallic resource. Aluminum occurs as terra rossa laterite, but is not presently mined.

Significant occurrences of base metals sulfides of Cu, Zn and Pb with associated Au/Ag have recently been proved. Other occurrences of metals include Mn, Cr, Ti and Fe oxides and minor Pt.

Limestone is the most important non-metallic industrial mineral followed by gypsum, marble, halite (salt), clay minerals, and small amounts of garnet and dolomite. The extensive clay mineral deposits have yet to be evaluated. The semi-precious stones of amber and pectolite are mined.

There are proved reserves of lignite and peat, but these are not presently mined. Non-economic occurrences of oil are known in the southern sedimentary basins.

Five significant hot spring occurrences are known associated with late Cenozoic volcanism and fracture zones in the southeast region. Their potential for geothermal energy has been evaluated.

## PETROGRAPHY AND GEOCHEMISTRY OF MAFIC ROCKS OF THE PERALVILLO FORMATION IN THE SABANA POTRERO AREA, CENTRAL DOMINICAN REPUBLIC

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Basalt pillow lavas and minor hyaloclastites intruded by crosscutting dolerites of similar composition, occur immediately north of the El Caribe serpentinized peridotite at Sabana Potrero in the Median Belt of the central Dominican Republic. The occurrence of massive sulphide within the mafic volcanics has given the opportunity for detailed study of samples from drill cores. The structural and stratigraphic information indicate that these mafic volcanic rocks form the base of the Peralvillo Formation of apparent Late Cretaceous age and are equivalent to the vitric and crystalline basalts of the Siete Cabezas Formation to the south of the peridotite belt.

The texture of the volcanic rocks ranges from fine-grained microporphyritic to poorly-developed ophitic to granular textures in the coarse-grained varieties. Clinopyroxene and plagioclase make up 90% of the rocks. The dominant alteration minerals are chlorite, phrenite, and epidote. Iron titanium oxide minerals are ubiquitously replaced by leucocene.

Mafic lavas and intrusives (dolerites) have been analyzed for major and trace elements mainly for the drill cores of the Sabana Potrero area, but also from surface exposures. Most of the rocks are olivine-hypersthene normative and some contain normative quartz.  $TiO_2$  ranges from 0.43 to 2.8% and varies with the  $Fe^{tot}/Mg$  ratio allowing correlations of different flow units between drill holes. Variation diagrams show that both the lavas and intrusive phases belong to a comagmatic sequence and that at least some of the lavas of the Siete Cabezas are comagmatic.

Chondrite-normalized Rare Earth plots show enrichment in Ce over La, depletion in Nd and a positive Eu anomaly. Trace element spider diagrams, normalized to N-Type MORB, show consistent patterns for all samples. Characteristic features are relative enrichment of Ce over La, 2 to 7 times enrichment in Nb and Ta, and slight depletion in Nd. Relative concentrations of Ti, Zr, Hf, Y are constant and similar to those of present-day ocean floor (MORB) basalts. These basalts are chemically distinct from the Duarte metabasalts.

# DRILLING SUBMERGED MARINE TERRACES OFFSHORE BARBADOS; AGES, ORIGIN AND SEA LEVEL HISTORY

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Studies of the timing of eustatic sea level changes have been refined using seismic and oxygen isotope data however the magnitudes of sea level changes in the geologic past are not known. Nowhere is this fact more evident than in the discrepancies over estimated sea level during the last glacial maximum. Estimates of mean ocean sea level during the last glacial low-stand range from 80 meters to 165 meters below present level. The exact timing of sea level rise during the last deglaciation is also poorly documented prior to 9,000 years before present.

In the Caribbean, the reef crest coral *Acropora palmata* is one of the dominant reef-framework builders. Its growth is generally restricted to the upper five meters water depth. This species thrives in the surf zone and is presently the best available sea level indicator. *Acropora palmata*'s narrow depth range, abundance in Caribbean reefs, good preservation, and massive size make it superior to molluscs or peats as an indicator of past sea level. Unlike molluscs or peats, corals may be dated by the newly developed <sup>230</sup>Th/<sup>234</sup>U dating method using mass spectrometry. This dating method eliminates the vagaries of C-14 age dating due to varying C-14 composition of local sea water.

In November, 1988, R/V Ranger, outfitted with a wire-line drilling rig and four-point mooring system, drilled sixteen cores into the three submerged terraces located offshore Barbados. More than 1200 feet of reef was cored, resulting in a nearly continuous sequence of *Acropora palmata* between 126 meters and 15 meters below present sea level. The longest core, which was 71 meters long, was collected in 74 meters water depth and sampled the glacial reef and beyond. C-14 measurements were made on several samples during the cruise in order to help guide site selection. C-14 dates indicate that vertical reef growth kept pace with rising sea level, and therefore a complete and detailed record of sea level rise during the last deglaciation is recorded in these cores.

Barbados is the only locality where the marine oxygen isotope record is calibrated against sea level documented with C-14 dated *Acropora palmata*. Similar drilling programs are possible in other tectonic settings and such studies will test for the first time, the accuracy of isostatic adjustment models.

# DIAGENETIC INDURATED MARINE BOTTOMS IN THE SOUTHERN PART OF BARBADOS WEDGE : EVIDENCE OF DEEP FLUID CIRCULATION

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The presence of wide indurated bottoms had been observed during DIAPICAR Cruise (Oct-Nov.1987) in the southern part of the Barbados accretionary tectonic prism. These indurated bottoms are located on the top of tectonic relieves (antiform ridges and mud-volcanoes) which result from convergence movement of Atlantic and Caribbean plates, involved in very important argillokinetic processes.

The indurated bottoms, upon which deep-sea communities are sometimes established were observed between depths of 1000 and 2200 meters. They present different morphological aspects. They generally show irregular and disrupted microrrelieves (cm to dm) in soft sediments areas supporting some currents-marks. Sometimes the bottom is covered by indurated blocks, scattered in the muddy sediments. They rarely show large concretions (dm to m) and similar to carbonate chimneys observed on Oregon margin. These discontinuous bottoms can cover very large areas (500 m. large and more 10 kms long). The indurated samples collected show brownish coating constituted of iron and manganese oxides with carbonate origin cement. The soft underlying sediments show very low carbonate contents (5 to 15%) and with a sometimes high proportion of hydrogen sulphide.

The origin of these encrusting cannot exclusively be linked to a marine environment, as cases of "classical" hard-grounds. We assume that the diagenetic processes responsible for sediment induration are controlled by deep fluid circulations and venting.

In fact, chemical analysis of interstitial waters in underlying soft sediments document dissolve chloride contents (293 and 485 mM/l.) lower than those of sea-water (550 mM/l.). Similar observations are used in O.D.P. Leg 110 sector to identify deep circulation located along the major thrusting faults of the accretionary prism. There, nevertheless, the minimum measured concentration is of 516 mM/l., so, consequently, the membrane filtration and deshydration of clay phenomenon which are invoked seemed insufficient to obtain such chlorinity values. The thermic decomposition of hydrate of methane levels observed on some high resolution seismic profiles (Bottom Simulating reflector) may be accountable of the decrease of chloride and also of an increase of methane concentration. The oxidation of methane into dissolved carbonates favours the precipitation of carbonate cement whilst a part of metallic ions (Fe and Mn) could be result of these fluids.

In conclusion, the indurated bottoms observed on this active margin, can be a main morphosedimentary characters. Their origin is supposed to be related with carbonate and metallic ions rich environment. They need the lift and venting of deep fluids driven by fractures and their position and expansion along NE-SV and E-W directions emphasize the most actual active structures of this region.

# QUATERNARY SEDIMENTS ON THE SOUTH BARBADOS ACCRETIONARY COMPLEX : A COMPARISON BETWEEN MUDDY-DIAPYRIC SEDIMENTS AND SOUTH-AMERICAN RIVER SUPPLIES.

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The tectonic context of the southern termination of the Barbados accretionary complex involves severe deformations as well as a strong dislocation of the prism's sedimentary cover with a tectonic network of various directions. Among these structures, numerous mud-diapiric relieves are present. Their morphology and tectonic features are clearly documented on seabed and seismic data and allow us to distinguish two kinds of diapiric structures : mud-volcanoes and anticlinal ridges.

Our objective is to characterize diapiric material in order to compare it with the supplies of South American rivers that are deposited in small adjacent basins.

On top of mud volcanoes or anticlinal ridges, the surficial diapiric sediments are clayey silty compact muds, with typical grey-lead or blue-green colors, low carbonate contents and many indurated muddy pebbles. Microfauna is rare and composed of late Miocene-Pliocene pelagical foraminifers. This material is covered by a thin layer of either Holocene soft mud or indurated diagenetic crusts. The clay mineral assemblage is composed of smectite associated with illite, kaolinite, and chlorite.

In the adjacent basins, on the contrary, surficial sediments are recent (last Glacial to Holocene) and are coarse-grained turbiditic layers interbedded in a grey-green slightly compacted mud. Their clay mineral assemblage show a significantly lower smectite content and are similar to the assemblage observed in the sediments provided by the Orinoco and Amazon.

On the slopes of the diapiric structures, the deposits are composed of superposed diapiric material and non-diapiric turbiditic sediments.

According to the age and clay assemblage of diapiric mud, we assume that these sediments are provided by Miocene deep beds : they are first ejected under tectonic stress then they incorporate younger sediments during their uplift.

The diapiric material thus expelled onto the top of the structures, is scattered on their slopes or into the adjacent basin by gravity processes. Because of the multiplicity of these structures, we suspect that argillokinetic processes are a significant source of sediments for the prism's deposits.

# CUBA: FORMACION DE OLISTOSTROMAS EN UN AMBIENTE DE COLISION ARCO INSULAR-MARGEN CONTINENTAL

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En el territorio de Cuba se desarrollan ampliamente depósitos olistostromáticos de diferente composición, génesis y edad. La formación de los olistostromas cubanos se relaciona con la colisión del arco insular cretácico con el margen continental mesocenoico de América del Norte. Este proceso se extiende desde el Campaniano hasta la parte baja del Eoceno Medio. Se distinguen tres tipos genéticos. El Tipo I se formó en cuencas superpuestas gracias a movimientos verticales que provocaron el ascenso energético del relieve montañoso de las islas del paleoarco insular cretácico. Estos olistostromas están poco deformados y forman horizontes más o menos potentes incluidos por lo general en depósitos terrígenos y se desarrollan en tres intervalos (Maestrichtiano, Paleoceno superior - Eoceno inferior, Eoceno inferior - Eoceno medio). El Tipo II está constituido por depósitos que forman una franja discontinua a lo largo del borde norte de la isla, marcando el obalgamiento de los complejos del arco insular cretácico y las ofiolitas, sobre el margen continental norteamericano. Son depósitos por lo general polimicticos, potentes, frecuentemente muy deformados, formados en el proceso de colisión del arco insular cretácico con el margen continental (Paleoceno superior - Eoceno medio). El Tipo III (Maestrichtiano-Paleoceno) está constituido por depósitos vinculados al desarrollo de una zona de rift, la cual escindió los complejos del arco insular cretácico a lo largo de la línea Cauto-Nipe. Al N.W. de esta línea (zona Auras), predominaba la compresión y se formó una compleja de estructura nape-escamada, acompañada de olistostromas muy deformados en cuya composición entran, fundamentalmente, rocas de la asociación ofiolítica. Al S-SE, en la propia zona de rift, en un ambiente distensional, se produjo la deposición de secuencias terrígenas con olistostromas y turbiditas ultrabásicas que forman un complejo muy particular.

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# EL PROBLEMA DEL EMPLAZAMIENTO DE LOS MACIZOS ULTRABÁSICOS DE LAS SIERRAS DE NIFE Y CRISTAL Y SU RELACION CON LA POSICION DEL FLYSCH TERRIGENO DE LA FORMACION MICARA

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La geología de la región situada al este y sureste del macizo de Sierra del Cristal es una de las claves para comprender la evolución tectónica del territorio de Cuba nor-oriental en el Cretácico Superior Paleoceno. Aquí, se desarrollan los depósitos terrígenos flyschoides de la Formación Micara ( $K_2 - P_1$ ), los cuales contienen numerosas horizontes de conglomerados polimíticos y de olistostromas de dos tipos: exolistostromas y endolistostromas. Los primeros están constituidos por un amontonamiento de bloques, desde uno hasta varios metros, de rocas fundamentalmente de la asociación ofiolítica (serpentinita, gabros, diabasas, etc.), casi sin cemento. Los segundos, por bloques irregulares del propio flysch encajante, englobados en una matriz aleurolítica de composición vulcanocítica. Además, aparecen numerosos olistolitos y olistoplaques, hasta de algunos cientos de metros, de serpentinita y turbiditas ultrabásicas. El carácter de la distribución de los sedimentos muestra que la fuente de aporte se encontraba al O.NO, es decir, en dirección al macizo de Sierra de Cristal. Alrededor de este último se extiende, como una aureola, una asociación de ultrabásitas brechosas y turbiditas serpentiníticas, la cual, según todas las evidencias, pudo haberse formado en condiciones de un emplazamiento rápido, acompañado de descomposición brusca, del macizo de Sierra de Cristal, en la paleo-cuenca de deposición de la Formación Micara. Esta asociación se interdigita en dirección submeridional con los depósitos flyschoides terrígenos de Micara, los cuales, tal como está establecido, yacen transgresivamente sobre los depósitos arcoinsulares cretácicos. El macizo Moa-Baracoa, como se sabe, cabalga en dirección N-S a los complejos de la zona oriental de desarrollo de Micara. Por su parte, los macizos de Sierra del Cristal y de Nipe, se vinculan con la posible escisión del arco insular cretácico a lo largo de la línea Cauto-Nipe, ocurrida probablemente en el  $K_2 - P_1$ , lo cual no había sido considerado hasta ahora.

# GEOLOGIA Y DISTRIBUCION DE LAS CROMITAS DE LOS MACIZOS OFIOLITICOS DE MAYARI Y MOA-BARACOA, REGION ORIENTAL DE CUBA.

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En la región oriental de Cuba afloran los mayores macizos ofiolíticos del país, denominados Mayarí el mas occidental y Moa-Baracoa el oriental. Ambos presentan diferencias en el desarrollo del perfil ofiolítico. En el macizo de Mayarí afloran los complejos ultramáfico metamorfiado, cumulativo ultramáfico y escasamente el máfico y los diques paralelos de diabasas. El complejo inferior aflora en la parte mas occidental y se caracteriza por la presencia de harzburgitas y lherzolitas. La mineralización de cromitas podiformes con altos contenidos de  $Cr_2O_3$ , se dispone en la parte central de este complejo en forma concentrica, empobreciéndose hacia el borde SW del mismo. Los contactos con los complejos cumulativos por el este de diques paralelos de diabasas por el oeste con tectónicos. En complejo cumulativo se desarrolla hacia Sagua de Tánamo y está representado por dunitas, dunitas plagioclásicas, troctolitas, gabros olivínicos. Se caracteriza por la presencia de cromitas más pobres.

La región de Moa-Baracoa, es una prolongación del bloque Mayarí. En él predominan los cumulos ultramáficos y máficos, los gabros masivos. Aquí las ultramafitas metamorfiadas afloran poco, sin embargo el complejo basáltico alcanza un gran desarrollo. Los contactos entre todos ellos son tectónicos, las fallas regionales coinciden con el contacto transicional entre la parte inferior y superior de los cumulos. La mineralización cromítica aparece en tres niveles dentro de los cumulos, el inferior en las dunitas enstáticas con cromoespinelas dactiloscópicas y kotsohubeita intersticial, el segundo nivel corresponde a la zona de transición entre las dunitas y las dunitas plagioclásicas y por ultimo entre los gabros bandedados y los masivos. Por la distribución de la mineralización, y por las características geológicas, se puede adoptar el modelo de Nicolas y Violette (1982) y suponer que el centro de expansión que dio origen a estos macizos ofiolíticos se encontraba en una posición cercana al de Mayarí

## GEOQUIMICA DE LA ASOCIACION OFIOLITICA DE CUBA

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La asociación ofiolítica de Cuba aflora en diferentes zonas estructurales, principalmente en la región septentrional del territorio y en aislados bloques emplazados en los macizos meridionales metamórficos. Aunque el grado de metamorfismo origina la migración y sustitución de algunos componentes, el quimismo de los complejos es similar. Los cuatro complejos que caracterizan a la asociación ofiolítica se distribuyen irregularmente, el complejo ultramáfico metamorfiado aflora principalmente desde Pinar del Río hasta Villa Clara, disminuyendo su presencia hacia la región oriental del país. A la inversa el complejo cumulativo alcanza su mayor desarrollo en la parte centro-oriental. Los complejos elusivos superiores se distribuyen en todo el territorio donde afloran las ofiolitas.

Geoquímicamente las dunitas del complejo ultramáfico metamorfiado presenta bajos contenidos de  $Al_2O_3$  en tanto en las harzburgitas del mismo complejo estos aumentan. Esto se debe a que la enstatita y las espinelas son los únicos minerales que contienen aluminio. Este elemento en el complejo cumulativo máfico aumenta con la aparición de los minerales félsicos. A medida que ocurre la cristalización fraccionada del complejo cumulativo, se origina un empobrecimiento en el magma de Ni, Co y Cr. En general en estos dos complejos inferiores los alcalis son extremadamente bajos, pero en los superiores existe un aumento progresivo que alcanza un máximo en los basaltos alíticos y boninitas especialmente el sodio. El Sr varía desde 0 en las ultramafitas hasta 141ppm en los gabros y en los elusivos alcanza has 196ppm. El V, el Ti, y el fósforo aumentan desde el complejo ultramáfico metamorfiado al cumulativo, ya que los dos primeros se concentran en la titanomagnetita y titanogaugita, tan característicos en los gabros y diabasas ofiolíticas, y el ultimo por su comportamiento tan semejante al Ti. A veces los contenidos de Nb son más altos en las ultramafitas serpentinizadas que en los gabros, debido a la hidralación de las rocas durante la serpentinización.

Se puede afirmar que la asociación ofiolítica de Cuba, por las variaciones geoquímicas tiene un origen máfico único, pero los complejos cumulativo y elusivo, presentan algunas variaciones litológicas y químicas entre diferentes regiones. Esto se explica para los cumulos por la presencia de cámaras ígneas aisladas, criterio que también pudiera ampliarse a los complejos superiores elusivos de la asociación ofiolítica.

## THE MINERALOGY OF BAHAMIAN SOILS

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The mineralogy of soils occurring on Eleuthera and San Salvador Islands, Bahamas was investigated. These soils represent immature soils forming in a relatively pure carbonate environment. The major factors of soil formation are as follows: 1)The climate is humid tropical savanna with an annual precipitation of 115 cm. 2)The parent material is carbonate eolianite plus airborne dust from North Africa. 3)Relief is low with a maximum elevation is 37 m. 4)The vegetation ranges from low density scrub to dense mixed broad leaf coppice.

Three major soil types, "Bahamas black loam", "Bahamas stony loam" and "Bahamas red loam" occur over consolidated limestones. These soils are thin, stoney and concentrated in shallow karst depressions. The limestone below the solum is altered and occurs as a laminar crust or Ck horizon. The carbonate content of the solum ranges from >90% to 3% and its presence results in a high soil pH (7-8). The mineralogy of the insoluble residue from each soil type is given below.

Soil Name and Type	Minerals Present
Bahamas Black Loam (Leaf mould soil)	Illite, Kaolinite, Quartz, Feldspar
Bahamas Stony Loam (Immature lateritic soil)	Mixed layered Hy-Al-IC/illite, Kaolinite, Quartz
Bahamas Red Loam (Aluminous lateritic soil)	Hy-Al-IC*, Boehmite, Quartz

\*Hy-Al-IC = hydroxy-Al interlayered clay

The "Bahamas black loam" contains unaltered silicate minerals similar to the airborne dust. Partial alteration of primary silicates is observed in the "Bahamas stony loam" which contain mixed-layered clays and lack feldspars. The alteration of the parent material is greatest in the "Bahamas red loam" which contain pedogenic hydroxy-Al interlayered clays (Hy-Al-IC) and boehmite.

Bahamian soils are modern analogs to paleosols which occur within carbonate sequences and represent relatively short intervals of subaerial exposure. An understanding of these soils will improve paleoenvironmental and stratigraphic interpretations of ancient carbonates.

## AN INTERPRETATION OF THE GRAVITY FIELD OF THE SE CARIBBEAN PLATE BOUNDARY ZONE

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To help test various models of its structure, we have studied variations in the character of the gravity field over the southeastern boundary between the Caribbean and South American plates. Crustal sections were constructed along 6 approximately north-south corridors between 60°W and 73°W from published compilations based upon seismic reflection and refraction data as well as geological interpretations. Composite regional gravity anomaly profiles comprising free air data over marine areas and Bouguer values on land were modeled using standard 2-dimensional techniques. Although the geometry of the bodies was varied from profile to profile to optimise the fit with the observed anomaly data, densities of individual bodies were kept constant so as to ensure compatibility between profiles and continuity of sources between adjacent corridors.

Results of the modeling suggest a west to east progressive change from a geometry more indicative of compressive conditions near Valencia to one that is consistent with predominantly strike-slip conditions near Maturin. Modeling of gravity features along a NW-SE profile west of Maracaibo does not require any significant subduction of Caribbean lithosphere beneath South America but rather can be adequately explained by modest amounts of underthrusting. Profiles to the east of the island of Tortuga are compatible with models involving the juxtaposition of arc material and a passive continental margin. Features in the gravity field suggest that the width of this arc material does not substantially change from west to east. At the extreme eastern end of the study area, modeling indicates that the localized loading imparted by the enormous amounts of Orinoco Delta sediments may overlie an oceanic basement.

## MAGNETIC ANOMALIES OVER THE COLOMBIAN BASIN, WESTERN CARIBBEAN SEA

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A new total intensity magnetic anomaly map of the Colombian Basin has been prepared from available marine data using a detailed cross-over analysis to minimize cross-tie errors. Although the anomaly field throughout much of the basin is characterized by low amplitude anomalies, the map also shows several distinct features. These include a series of localized, higher amplitude (200nT) anomalies over the Hess Escarpment and a small area of E-W trending linear anomalies (150-200nT) between 11-15°N, 74.5-77°W. Dominant positive anomalies are found north of the Hess Escarpment and negative anomalies to the south. Anomalies over the northeastern portion of the Lower Nicaraguan Rise are typically 150-250nT with wavelengths of 80-100 km.

To constrain possible sources of the E-W magnetic anomalies, both marine and satellite derived gravity anomaly data were examined for possible correlations. It has been suggested, the magnetic anomalies are due to basement relief, then there should be corresponding gravity highs and lows. No such features are observed and the anomaly field is found to be rather flat with only a minor NE-SW trend that cuts across the magnetic trends. Seismic reflection and refraction data indicate a thickened sedimentary section which is also not reflected in the gravity data. The absence of a significant gravity low over the area suggests the presence of high density material at shallow depths. Although this material may be intracrustal, refraction data are more compatible with a substantial shallowing of the Moho to depths more consistent with "normal" oceanic crust. The magnetic anomalies are, therefore, interpreted to be those produced by a piece of normal oceanic crust surrounded by thickened, sill-laden crust.

Insufficient features are present to obtain meaningful correlations of the magnetic anomalies with those produced by late Mesozoic spreading. As an alternative approach to determining the age of this oceanic crust, a paleomagnetic pole position has been determined from a deskew analysis of linear anomalies in the Venezuelan and Colombian Basins. Lines of confidence from this analysis intersect near 45°N, 145°W yielding a pole that places the Colombian Basin at approximately 24°N at the time the oceanic crust formed. The deskew analysis also gives a declination of N 40°W suggesting a counterclockwise rotation of the seafloor since its formation. To determine when the Colombian Basin was located at this latitude and thereby obtain an age for the magnetic sources, we have rotated the area of E-W anomalies about Caribbean-North America rotation poles between 0 and 84 MyBP, and then about Farallon-North America poles between 84 MyBP and 160 MyBP. The area initially tracks westward out of the Caribbean region and then moves northward during the late Jurassic-early Cretaceous crossing 20-25°N sometime in the Jurassic. We therefore interpret the E-W area as a piece of oceanic crust formed at the Farallon Ridge sometime in the Late Jurassic-Early Cretaceous. Such an age is broadly compatible with previous magnetic studies in the Venezuelan Basin which identify the anomalies there as those produced in the Early Cretaceous. Rotation of the Colombian Basin about the North American poles also produces a counterclockwise rotation consistent with the declination given by the deskew analysis.

## NEOGENE SEDIMENTARY EVOLUTION OF ST. CROIX, U.S. VIRGIN ISLANDS

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St. Croix is a dominantly sedimentary island in the northeastern Caribbean and its sedimentary development is therefore of considerable relevance to regional tectonic reconstruction. Previous models of the late Tertiary development of St. Croix assume either that the carbonate sediments were deposited in 1) shallow water or 2) entirely within the confines of an insular graben system. Both models presume a static, isolated island with a self-contained sediment source. Evidence from our drilling program on St. Croix requires modification of both models of basin evolution. Pelagic and hemipelagic carbonates of the Kingshill Limestone overlie blue pelagic and hemipelagic carbonates of the Jostouy Formation with a sharp, diachronous lower-to-middle Miocene boundary that ranges between planktonic foraminiferal zones N8 and N10. The Jostouy Formation itself is a deep-water limestone indistinguishable from the Kingshill Limestone except by color. Based on all known samples taken from it, the Jostouy Formation is a Miocene unit, not Oligocene, and does not outcrop.

Benthic foraminiferal faunas from drill samples suggest that most of the Neogene section reachable by drilling was deposited in the upper bathyal zone. Pronounced shallowing did not occur until the latest Miocene to early Pliocene. Samples collected from the western side of the basin show no sedimentologic or paleoecologic evidence of shallowing, faulting or a nearby landmass during early Miocene deposition of the Jostouy Formation. However, coarse clastic debris in Kingshill Limestone exposures along the eastern fault zone indicate that faulting and graben formation had begun at least prior to the latest middle Miocene.

This evidence indicates that the Jostouy Formation and the Kingshill Limestone began deposition prior to graben formation, and that faulting or horst exposure began later in the middle Miocene. A source external to the present structural basin is required to produce the pre-graben, shelf-derived carbonate components; we suggest that they originated from source areas to the north such as Puerto Rico or the Virgin Islands Platform. It appears likely that St. Croix has migrated and was uplifted in the Neogene, possibly during the opening of the Virgin Islands Basin and the Anegada Passage. The creation of these seismically active features was probably dominated by transtensional movement with a significant left-lateral component of slip.

## EVALUATING GROUNDWATER MIXING AND SEAWATER EVAPORATION DURING DOLOMITIZATION, ST. CROIX

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This project utilizes the chemistry of the modern groundwater, as well as the chemistry, distribution and petrologic aspects of the dolomite to test various models of dolomitization on St. Croix. Dolomite on St. Croix exists in a highly localized region of outcrops and subsurface strata in a Pliocene reef tract. The dolomite occurs in reef, lagoon and platform facies that rim the pre-development shoreline of Krauss Lagoon. Below the present water table, dolomitized rock follows the thickened under-surface of the same lagoon. Despite the existence of similar facies elsewhere on St. Croix, the dolomite is found nowhere else. This spatial distribution suggests that the formation of the dolomite was genetically related to hydrologic conditions found in Krauss Lagoon.

The  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopic composition of the dolomite is  $0.70887 (\pm 0.00002)$ , which corresponds to the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of Miocene seawater. However, the dolomite resides in Pliocene strata, making a Miocene dolomitization event unsupportable and requiring a significant external source of non-radiogenic strontium. St. Croix groundwater  $^{87}\text{Sr}/^{86}\text{Sr}$  ranges from 0.7076 to 0.7085, well below the ratio of both modern seawater and the dolomite. Mixing calculations show that St. Croix groundwater could be a significant source of non-radiogenic strontium in a dolomite formed from a two-component groundwater-seawater mix.

Stable isotopic values for the dolomite range from  $+0.7$  to  $+3.0$ ‰  $\delta^{18}\text{O}$  and from  $+0.6$  to  $+2.4$ ‰  $\delta^{13}\text{C}$  relative to PDB, with an enrichment trend from the margins to the center of the lagoon. The maximum oxygen isotopic values reached in these dolomites are too enriched in  $^{18}\text{O}$  to be formed from groundwater or seawater, even accounting for ice-volume effects. These data imply that dolomite precipitated from fluids enriched in  $^{18}\text{O}$ , probably as a result of evaporation. In order to account for the geochemistry and geologic distribution of the dolomites we suggest that dolomitization took place from fluids that were produced from a mixture of evaporated seawater and groundwater. Calculations show that such a scenario is possible, and may be geologically more common than one would suspect. In addition, the calculations show that groundwater effects on the strontium isotopic composition of carbonates cannot be ignored *a priori*, and the dating of carbonates in similar geologic environments should be approached with this in mind.

# HIGHSTAND SHEDDING OFF TWO 'SEMI-DROWNED' SHALLOW CARBONATE SYSTEMS, PEDRO BANK AND THE SOUTHERN SHELF OF JAMAICA, NORTHEASTERN NICARAGUA RISE

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Water depths on (1) Pedro Bank, an isolated carbonate platform and (2) the southern shelf of Jamaica, an attached mixed carbonate/siliciclastic system, average 20 to 30 m. Because the tops of these carbonate systems did not keep up with the Holocene sea level rise, and because they are usually covered by only a thin veneer of bioclastic (algal-sponge-coral-foram) sandy sediment, they have been considered to be "drowned" or "semi-drowned". Analyses (size fraction separation, carbonate content and mineralogy, radiocarbon dating of bulk sediment and foraminiferal biostratigraphy) of four cores from Walton Basin, an open seaway between Pedro Bank and the southern shelf of Jamaica, clearly exhibit current overproduction and highstand shedding of metastable bank derived fine aragonite and magnesian calcite.

For comparative study, we have selected two sets of two 5.5 to 6.0 m long piston cores, located in close proximity to either Pedro Bank or the southern Jamaican shelf. The cores were collected at comparable water depths (300 and 500 m) and close to the bank and shelf edges, 2 to 3 km and 6 to 8 km respectively. The carbonate content of glacial/interglacial sediments just off Pedro Bank, remains almost constant and averages 93%. Whereas, the carbonate content of sediments deposited off the southern Jamaican shelf varies between 45% for Holocene sediments and 70% for sediments deposited during the last glacial to interglacial transition. Based on radiocarbon dating, sedimentation rates during the past 5000 years in the cores nearest to the bank and shelf edges range between 2000 mm/ky off Pedro Bank and 1300 mm/ky off the Jamaican shelf. Sedimentation rates drop significantly for the more distant cores, to 45 mm/ky during the Holocene off Pedro Bank and to 400 mm/ky (carbonate rate) off the Jamaican shelf. Glacial sedimentation rates in the most distant core off Pedro Bank reached only 10 mm/ky. The 3.5 kHz record shows a well defined sediment wedge thinning away from the bank and shelf edges. One of the cores off the southern Jamaican shelf has penetrated the 6 m-thick sediment wedge and has reached its basal erosional unconformity. Based on radiocarbon dates, we can show that this wedge corresponds to the last sea level transgression and the subsequent Holocene flooding of the southern shelf. The drastic changes of sedimentation rates, coarse fraction proportion, carbonate content, and carbonate mineralogy, dated at 9000 years B.P., correspond well with the estimated time of shelf flooding.

# FOSSIL ECHINODS OF THE LATE PLEISTOCENE FALMOUTH FORMATION (REEF TERRACE 1) OF JAMAICA'S NORTH COAST.

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It is generally believed that there has been minimal faunal change in the marine community between the last interglacial and the present. This is based primarily on empirical data derived from benthic molluscs (Richards, 1962, Studies on the Marine Pleistocene, Transactions of the American Philosophical Society, 52, 1-141) and coral reef communities. It is not known if this is also true for other marine invertebrate groups. This study attempts to determine whether or not the echinoid faunal composition has changed since the Pleistocene. The highly fossiliferous Falmouth Formation (Reef Terrace 1: approx. 125,000 yr BP) of Jamaica provides an ideal subject for such a study. Furthermore, the Recent echinoid fauna of the Caribbean is a manageable subset of the global echinoid fauna for critical comparison.

In Jamaica there are 17 extant species of echinoid (Clark 1933, A handbook of the littoral echinoderms of Porto Rico and the other West Indian islands. New York Academy of Science Scientific Survey of Porto Rico and the Virgin Islands, 16, 1-147; Dr. J.D. Woodley written comm.), yet only 9 fossil species have been described from the entire Plio-Pleistocene interval (approx. 5 Myr) of the island. It is believed that this disparity is only apparent and is partially due to the rapid disarticulation of the multiplated echinoid test. Disarticulated echinoid plates are locally common in the Falmouth Formation.

Research to date has yielded the test from a juvenile *Echinometra* sp. along with abundant radiolaria test plates from *Astrorhiza* sp. and/or *Diadema* sp., *Echinometra* sp., and spatangoids. Ossicles of the Aristotle's Lantern and other plates have also been recognized, but have yet to be classified. Additionally, the disarticulated ossicles from ophiuroids have also been found to be abundant.

Irregular echinoids have a better fossil record than regulars but, when dealing with disarticulated material, fragments of regular echinoids are easier to detect and identify.

# PALEOCEANOGRAPHIC AND PALEOCLIMATIC RECONSTRUCTION FROM 500 YEAR OLD CORALS, *MONTASTREA ANNULARIS*, IN THE SHELF OFF LA PARGUERA, PUERTO RICO

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Specimens of the hematyptic coral *Montastrea annularis* have been found in the shelf off La Parguera, southwestern Puerto Rico, which are at least 4-5 meters in height. Colonies of this size are uncommon elsewhere in the Caribbean. *M. annularis* forms distinct annual growth bands which result from the differential deposition of CaCO<sub>3</sub> throughout the year. We have counted the growth bands for the entire length of the specimens and calculated their growth rate. These specimens, 4-500 years old, offer the means to reconstruct aspects of the regional climatic and oceanographic history for at least the life of the colony. An important aspect in this study is the potential to separate natural environmental changes from anthropogenic influences, such as the burning of fossil fuel and increased CO<sub>2</sub> in the atmosphere which results in the greenhouse effect.

# ACTIVE TECTONICS OF THE CHORTIS BLOCK

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Internal deformation of the Chortis block (Honduras, El Salvador and environs) is controlled by two well defined, seismically active plate boundaries on the north and on the southwest. Much of the Chortis Block is included in either the CARIB/COCOS plate boundary zone (convergence rate=8 cm/yr) or the CARIB/NOAM plate boundary zone (slip rate=2 cm/yr). The Nicaraguan depression is a marginal basin responding to subduction from the Middle America Trench. The depression crosses the Gulf of Fonseca and continues into El Salvador where it is not as prominent a topographic feature. The Motagua and Polochic faults are the two major, active CARIB/NOAM plate boundary faults in Guatemala. Several faults with similar orientations occur south of these faults within the present Chortis block. The most prominent of these faults is the Jocotán-Chameleón fault which is not active (Clemens, 1966). However, several similar faults may be active, e.g., the Aguan, La Cebosa, and Pueblo Nuevo faults across northern Honduras. The CARIB/COCOS plate boundary is much more seismically active than is the CARIB/NOAM plate boundary. The intraplate deformation of the Chortis block, paradoxically, seems to result primarily from motions along the CARIB/NOAM plate boundary.

North-trending basins with north-striking normal faults define the Honduras depression, a major zone of intraplate deformation entirely within the Chortis block. It is seismically active as demonstrated by instrumentally recorded earthquakes (NEIS Catalog), historical earthquakes (Oslecki, 1981), and Quaternary fault scarps. The principal basins are connected by a series of poorly defined, right-stepping strike-slip faults which strike northwest (Emmett, 1983). These faults may be a reactivation of a Late Cretaceous structural trend. Similar basins occur off the principal axis of the Honduras depression (e.g., the Jesús de Otoro, Talanga, and Santa Bárbara basins) indicating that the region as a whole is experiencing dextral shearing which reactivates old faults and forms extensional basins between principal fault segments. The most prominent extensional corridor of the Sula valley, Lake Yojoa and the Comayagua Valley probably represents the most profound preexisting weakness. Other extensional basins occur south of the CARIB/NOAM plate boundary in Guatemala (e.g., the Guatemala City and Palá grabens). These basins are actively forming as was shown by the aftershock pattern of the 1976 Guatemalan earthquake (Pflafer, 1976). These aftershocks indicate that north-striking normal faults form within the Chortis block as a result of strike-slip faulting on the plate boundary.

The Guaysape fault is the longest, continuous structural feature in Honduras. It extends 190 km southwest from the Caribbean coast to the Jamastrán Valley region. An extension of the fault, the Choluteca lineament, may continue through Neogene volcanic deposits to the Gulf of Fonseca. In spite of its sharp, well-defined topographic signature, little seismic activity in this region was found in the NEIS Catalog between 1963 and 1983, or from the historical record (Oslecki, 1981). Our recent geologic mapping in the Catecamas Valley and the geometry of other basins show that the Guaysape fault has a right-lateral sense of slip. Even though the Guaysape fault represents important intraplate deformation, a direct relationship between it and the deformation at the plate boundary is not readily apparent.

# STRATIGRAPHIC IMPLICATIONS OF PALEOMAGNETIC DATA FROM HONDURAS

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Paleomagnetic results from mainly Cretaceous rocks in Honduras delineate a distinctive apparent polar wander path which is well suited for magnetostratigraphy. Our interpretations are based on the comparison of magnetic pole positions of undated rocks with pole positions from rocks which had been dated either by fossils or radiometrically. Using these "calibration points", we were able to resolve stratigraphic problems that have defied normal field mapping and correlation studies. These results demonstrate the power of magnetostratigraphy in the absence of fossils or marker beds, and for areas of discontinuous exposures. For regional interpretations the most important conclusion is that the clastic strata in Honduras, which were formerly assigned to the Todos Santos Formation, were deposited on a different tectonic plate than the true Todos Santos Formation of Guatemala and southern Mexico. The name "Todos Santos Formation" should be abandoned in Honduras and for the entire Chortis Block. The other findings are mainly of local significance: 1. The non-fossiliferous exposures of red beds belonging to the Valle de Angeles Group, can be assigned to either the upper or lower member based on their direction of magnetization. 2. The upper Valle de Angeles beds, at least where sampled for this study, are of upper Cretaceous age, not Tertiary as reported in earlier literature. 3. The Guare limestone is the upper member of the Jaitique Formation as defined by Finch (1981). 4. The Jaitique Formation is older than the Esquías Formation, and the Esquías limestone seems to be younger than the generally quoted Cenomanian age. 5. The Plancitos Formation is of Cretaceous age and probably contemporaneous with the Barremian/Aptian Cantarranas Formation.

# A LATE TERTIARY PALYNOFLORA AND TERRESTRIAL PALEOENVIRONMENTS FROM HAITI

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In 1923 E. W. Berry published on a small collection of fossil plants made by W. P. Woodring from Haiti. Identifications included the alga *Chara*, the fern *Gymnogramma*, and the angiosperms *Bumelia*, *Chrysophyllum*, *Guettarda*, *Mespilodaphne*, *Mimusops*, *Pisonia*, and *Simaruba*. Early identifications of leaves of tropical plants have proven notoriously unreliable, and the flora has not been studied since Berry's work. Recently permission was received to remove small pieces of the outer matrix of the Haitian specimens to process for pollen and spores. The microfossils recovered include monolete and trilete fern spores, the tree fern *Pteris* (abundant), pollen of the gymnosperm *Pinus* (pine; abundant), and pollen of the angiosperms *Palmae* (palm), *Alchornea*, *Chenopodiaceae/Amaranthaceae*, *Compositae* (common and several types), *Engelhardia*, *Hygrophila* (first fossil record), *Malpighiaceae*, *Myrtaceae*, *Oryctanthus*, and various unknowns. From the very general locality data on the specimens they are likely from the Maissada Formation, and the palynomorphs indicate a maximum age of uppermost Miocene to Pliocene. Preliminary results suggest the vegetation was similar to that presently growing on the island, including the pine forests now a prominent community on Haiti. The paleoclimates were also similar to those presently prevailing at low to mid-altitudes.

# PALEOMAGNETIC RESULTS FROM THE SOUTHERN CARIBBEAN PLATE BOUNDARY ZONE

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We collected 729 rock samples of mainly Cretaceous age at 46 sites in Venezuela for paleomagnetic studies with the aim of assessing the tectonic stability in the southern Caribbean plate boundary zone. 13 sites are located in the Serranía de Perijá, 22 sites in the Mérida Andes, and 11 sites in the Serranía del Interior. The data are of very good quality and constitute an internally consistent data set, quite in contrast to previously published data from this region.

The samples from the Mérida Andes yield well-grouped directions of both polarities. These data imply that the Andes have not undergone any significant motion relative to cratonic South America. This is the expected (and re-assuring) result because the Andes are anchored to the shield by the Precambrian Mérida Arch which was a positive structure throughout the Cretaceous.

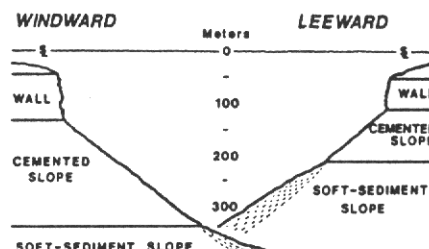
By contrast, all samples from the Perijá Range in western Venezuela have north-east or south-west declinations and the inclinations closely correspond to their present latitude. The data suggest that the Perijá range was once a linear continuation of the Santander Massif. In the north, the Perijá is truncated by the east-west striking Oca fault for which a right-lateral translation of a few tens of kilometers has been inferred. The rotation of the Perijá could account for about 200 km of dextral offset between the Caribbean and South American plates, a displacement which would not be expressed as a fault offset. This translation is small when compared to the 1100 km of offset along the northern Caribbean plate boundary but future studies in this plate boundary zone may show additional translations.

The data from the Serranía del Interior in eastern Venezuela are in part remagnetized (negative fold test), but most sites indicate no or a small (<10°) clockwise rotation. The lack of significant block rotation in this strike-slip zone implies either that no major strike-slip motion occurred between the eastern Caribbean and South America or that plate boundary lies to the north of the coast line.

# WINDWARD VS. LEEWARD PLATFORM MARGINS AND THE EFFECT OF LOCALIZED SHELTERING, TONGUE OF THE OCEAN, BAHAMAS

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Submersible dives to -350m along the platform margin in the southern portion of the Tongue of the Ocean (TOTO), Bahamas indicate distinctive patterns of sediment accumulation related to windward and leeward positioning (see figure). The most striking feature is the variable thickness in the wedge of unconsolidated, fine-grained sediment overlapping the cemented slope. Leeward transects show a significantly higher upper limit of soft sediment onlap (about -215m) than the windward margin (about -340m), presumably as a result of fine-grained sediment being carried off the open platform. Further north, where the leeward margin is partially sheltered by the Ezuma chain, less fine-grained sediment accumulates (top at -290m). Total thickness of the near-vertical wall also reflects variations due to windward vs. leeward orientation. Windward margins typically have a wall that extends for 80-100m whereas leeward walls are only 50-60m thick. Variations in wall thickness are probably due to increased sediment supply at leeward margins. Observations indicate that sand-size sediment is transported downslope from the margins of the platform to the cemented slope below. Increased sedimentation rates on leeward margins would result in relative reduction in the vertical expression of the wall. These observations support the concept of rapid lateral growth on leeward margins and suggest that localized variations in sheltering effects may strongly influence carbonate platform growth.





# MORPHOLOGY AND DEVELOPMENT OF MODERN CARBONATE SLOPES, TONGUE OF THE OCEAN, BANANAS

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A thorough understanding of modern slope environments is essential to the interpretation of inclined deposits (clinoforms) from seismic profiles and outcrops of ancient reefs and platform margins. Recent work in the Tongue of the Ocean (TOTO) indicates that modern carbonate slopes are forming by the syndimentary amalgamation of linear trains of sediment and talus derived from the margin of the platform. In addition, our observations during 84 dives in the research submersible DELTA indicates that the upper slopes of TOTO exhibit a distinctive morphology: 1) the platform margin, which consists of a Holocene sediment wedge situated behind one or more areas of deep reef growth. These deep reefs, where present, are dissected by a series of sediment chutes; 2) the near vertical wall with slopes ranging from 70° to 90°, consists of variable types of deep corals, encrusting coralline algae, sponges, and green algae. The surface of the wall is characterized by small pits, caves, ledges, and vertical overhangs. This zone is capable of producing copious amounts of sediment which is subsequently transported downslope. Transition from the wall to the underlying cemented slope is often characterized by large talus blocks, up to 30m in height; 3) the cemented slope, with a consistent slope angle between 35° and 40°. The surface often shows an irregular surface of hummocks and moguls separated by streams of loose sediment. Samples from this zone reveal submarine cemented sediment and reef talus. In some areas, large promontories project from the slope that may have been formed by the repeated cementing of numerous generations of talus blocks and sediment; and 4) a soft-sediment slope (25°-30°) which overlies the cemented slope. This sediment wedge exhibits varying surface morphologies ranging from a smooth sediment blanket to a series of large sediment ridges and troughs. Transition between cemented slope and soft-sediment slope is often marked by a zone of talus blocks. The sediment consists of a mixture of platform-margin derived sands and muds, and deep-water planktic material.

These results further refine the upper slope facies and elucidate the complex and heterogeneous nature of slope development.

# TAPHONOMIC BIASING OF SUBFOSSIL ECHINOID POPULATIONS ADJACENT TO ST. CROIX, U.S.V.I.

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The distribution of live and dead echinoids was compared in fore-reef, reef and shallow subtidal environments along a 720 m transect in Smuggler's Cove, and a 50 m transect in Rod Bay, St. Croix. Although echinoids are generally regarded as ubiquitous in shallow reef and adjacent environments, their distributions in Smuggler's Cove and Rod Bay are patchy. No intact tests of dead individuals were found associated with the living fauna, and comparison of live echinoid distribution with sediment composition awaits further constituent particle analyses. The lack of association of live and dead faunas suggests that echinoids are quickly acted on by bioturbation (post-mortem) processes; their preservation, therefore, may require extraordinary circumstances. One such circumstance may have occurred during March, 1984, when mass mortality decimated populations of *Diadema antillarum* adjacent to St. Croix. Tests and spines of this species were observed accumulating in seagrass beds immediately leeward of the reef tract in Smuggler's Cove shortly after the mass mortality. In 1988, a piston core taken from one of these beds was analyzed centimeter by centimeter to determine whether an horizon unusually rich in *Diadema* skeletal elements was preserved as a consequence of the baffling and binding properties of *Thalassia*. No horizon is evident in the greater than 2 mm size fraction; analysis of the smaller size fractions in thin section is ongoing. The probable lack of a "*Diadema* spike" in an environment of net sediment accumulation suggests that tests of *Diadema* degrade so rapidly that increasing the amount of subfossil material as a consequence of mass mortality alone was insufficient to preserve the event.

Decay experiments using specimens of *Diadema*, *Echinometra* and *Eucidaris* indicate that, in the absence of rapid burial, *Diadema* disarticulates most readily. Spines begin to fall off within 3 days of death and the periostracum begins to decay. After 5 days, the apical system collapses into the corona and the Aristotle's lantern begins to protrude from the peristome. In this condition, the slightest disturbance causes the test to disarticulate along ambulacral plate sutures. Tumbling experiments with additional echinoid skeletons reveal differences in relative durability of the test as well as the amount of material that is contributed to various size fractions. Results of laboratory experiments and field work suggest that *Diadema* may be particularly vulnerable to taphonomic bias - a conclusion currently being tested by an extensive review of its fossil occurrences.

# COMPOSITION AND DIAGENESIS OF CARBONATE SEDIMENTS ON THE ISLAND SHELF EAST OF HELLSHIRE, JAMAICA.

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Except for the northern region which contains mixed carbonate-siliciclastic material, sediments on the island shelf off the Hellshire coast are essentially pure calcium carbonate.

Major components in order of decreasing abundance are *Halimeda* plates, cryptocrystalline grains, mollusc fragments, intraclasts and articulated coralline algae. Minor constituents are foraminifera, encrusting coralline algae, echinoderm fragments, bryozoan, octocoral spicules, coral fragments, barnacle fragments and aggregate grains.

The distribution of the major components is influenced by mud dilution in the northern region, availability of hard substrate, biotic environment and physical processes related to wave energy.

Several early diagenetic processes affect the sediments. Encrustation by red algae is quite common. Aggregation has resulted in the formation of intraclasts and aggregate grains, the latter being aided by sediment infilling and cementation within empty scaphopod shells. Grains exhibit varying degrees of micritization ranging from micrite envelopes to cryptocrystalline grains. The following list shows decreasing susceptibility to micritization of various skeletal carbonate grains: *Halimeda* plates and coralline algae, mollusc fragments, foraminifera, coral fragments, echinoderm fragments. The susceptibility has direct implications regarding preservation of sediment texture during later stages of diagenesis.

# KINEMATIC HISTORY FOR EASTERN MARGARITA ISLAND, VENEZUELA

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Amphibolites, serpentized ultramafics, leucocratic igneous rocks, quartzofeldspathic and graphitic schists and minor marble make up the metamorphic nucleus of Margarita Island. Similar rocks occur along the Caribbean-South American plate boundary region from Tobago to Barquisimeto, exposed in the Cordillera de la Costa belt. The assemblage has been further subdivided into several related Mesozoic metamorphic belts, with Margarita belonging to a narrow band of rocks along the coast characterized by occurrences of high pressure metamorphic assemblages.

On Margarita Island, eclogite knockers in both the schists and the amphibolites spawned considerable work on the metamorphic history of the island. However, the corresponding kinematics were unknown. This study examined small-scale structures to infer a kinematic history for Margarita Island. The results shed light on the origin of the Mesozoic metamorphic belts and the plate tectonics required to form these rocks.

The earliest phase of deformation ( $D_1$ ) preserved on Margarita Island is rarely observed, seen as a foliation within microlithons bounded by the foliation of the next deformation ( $D_2$ ). This phase of deformation, synchronous with epidote-amphibolite to greenschist facies metamorphism, formed the dominant metamorphic foliation found on the island which is axial planar to associated isoclinal folds. Late in this stage of deformation, CS and quartz c-axis fabrics show SW-NE extensional deformation. In the Oligocene (?), another phase of deformation ( $D_3$ ) folded this  $D_2$  foliation into an anticlinorium that plunges to the SW. The latest brittle deformation ( $D_4$ ) also shows SW-NE extension.

All fold axes and extensions are aligned SW-NE. This is best explained by a consistent component of dextral strike-slip deformation since the Cretaceous. The observed changes in deformation reflect variation in depth and local bends in the plate boundary. This model for the kinematic history of the deformation on Margarita Island implies that these rocks were formed far to the west, perhaps in Pacific-South American plate interactions, with the preserved deformation reflecting the long-term dextral transport of these rocks along the Caribbean-South American plate boundary.

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An intensive search for hydrocarbons in the Mosquitia Basin of Nicaragua and Honduras began in 1961 when Pure Oil acquired a 5,900 hectare lease in eastern Honduras. By 1981 most exploration operations had ceased, ending a 20-year campaign that saw more than 22 oil companies exploring the basin. A total of 35 wildcats and delineation wells were drilled. Prior to 1961, only 4 wells had been drilled in the basin.

Pure's initial exploration efforts were directed onshore Honduras but shifted offshore in 1966 after Pure merged with Union Oil Company of California (now Unocal). Gravity, magnetics, and 7,800 miles of seismic data were acquired and used to support the drilling of 4 wells in Honduras, one of which yielded subcommercial oil and gas shows. Union's Honduran lease was allowed to lapse in 1977.

Offshore Nicaraguan leases adjacent to the Honduran holdings were secured by Union in 1966 and an exploration program was conducted in concert with the Honduran effort. Additional leases were granted in 1974, bringing the total Nicaraguan holdings to 1,198,000 hectares. Nearly 2,600 miles of seismic data were acquired and 6 wells were drilled. As in Honduras, commercial quantities of oil were not found, despite the fact that several wells flowed low rates of oil. Union's Nicaragua leases were relinquished in 1980.

The lack of success in the Mosquitia Basin was principally credited by Union to a lack of reservoir development. Facies models were used to predict porosity trends and to help select drill sites from numerous structural and reefal anomalies, but these models were not helpful in locating hydrocarbon accumulations. Future exploration efforts will rely on better understanding of sedimentary facies and deeper reservoir objectives.

#### NUEVOS ASPECTOS ACERCA DE LA GENESIS DEL PROTOLOITO DEL COMPLEJO ANFIBOLITICO MABUJINA, SUR DE CUBA CENTRAL

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El complejo anfibolítico Mabujina (CM) ahora en la parte sur de Cuba Central, formando una faja de anchura variable que rodea tectónicamente a las secuencias jurásico-cretácicas metamorfitizadas que constituyen al macizo de Escambray. Esta constituido principalmente por rocas básicas metamorfitizadas en la facies anfibolítica en condiciones de alta relación T/P, deformadas y foliadas de manera muy heterogéneas. Una porción considerable del CM procede de una típica asociación oíolítica. Esta comprende principalmente anfibolitas y, además, piroxenitas hornblendizadas, microgneises y peridotita serpentinizada. El complejo más caracterizado es el cumulativo bandeado, dado por una alternación de gabros piroxeníticos con diferente granulosis (desde pegmatíticos) con intercalaciones frecuentes de piroxenitas con distinto tamaño del grano y en algunas porciones de peridotita. También se destacan anfibolitas de grano fino y microgneises, cuyos protolitos responden al complejo de diques paralelos y al complejo vulcanógeno. Cabe señalar, que los análisis geoquímicos de 8 muestras diferentes demostraron que el contenido de algunos elementos inmóviles estables ( $\text{TiO}_2$ ,  $\text{FeO}$ ,  $\text{MgO}$ ,  $\text{V}$ ,  $\text{Cr}$ ,  $\text{Sr}$ ,  $\text{Zr}$ ) concuerda satisfactoriamente con el campo MORB. Otra parte del CM parece proceder de secuencias pertenecientes al arco volcánico cretácico. Los análisis geoquímicos de 3 muestras diferentes arrojaron una tendencia distinta. A veces se trata de unas anfibolitas esquistosas con numerosos restos de fenocristales de plagioclasa magmática, la cual es característica para las muestras analizadas. Con esta pueden relacionarse algunos cortes compuestos por metaglomerado volcánicos y metabasaltos porfíricos con fenocristales de clinopiroxeno hornblendizado. También tenemos los cuerpos de gneises leucocráticos granitíferos, cuyo protolito corresponde a los propios granitoides vinculados con el arco con el arco volcánico.

De aquí, que el protolito de una gran parte del CM se trata de una asociación oíolítica que constituyó el fundamento sobre el cual evolucionó el arco volcánico cretácico. Otra porción del CM procede de las propias secuencias de la parte más baja del arco volcánico. Todas estas rocas se metamorfitizaron y deformaron conjuntamente en las condiciones de alta relación T/P vinculado genéticamente con el alto gradiente geotérmico que tuvo lugar en la región donde se desarrolló el arco volcánico.

#### Ostracode Biostratigraphy of the *Titanosarcollites* and Oyster Limestone Beds and Associated Facies (Upper Cretaceous) of Jamaica

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Certain Cretaceous lithostratigraphic units of Jamaica of late Campanian to early Maastrichtian age are rich in ostracodes. About 175 species have been identified, nearly all of which are new to science. Important species of the fauna belong to the genera *Aequacythere*, *Asciocythere*, *Brachycythere*, *Buntonia*, *Limburgina*, *Ovocythere*, *Cleocythereis*, *Focythere*, *Schizocythere*, and *Alatocythere*. The generic assemblage is distinctly different from the well-known fauna of the North American Coastal Plain. The presence of *Ovocythere*, *Buntonia* and *Schizocythere*, particularly, relate the Jamaican assemblage biogeographically to Tethyan assemblages described from Africa and southern Asia. At the species level there are three distinct assemblages that succeed each other in time and are proposed as biostratigraphic zones. The oldest of these, which is associated with the *Titanosarcollites* beds and related shales, has been identified from the Central, Maldon, and Marchmont Cretaceous Inliers. It can be divided into three subzones that are useful for correlation between these inliers. The two younger zones have been found only in the Jerusalem Mountain Inlier of western Jamaica. The oldest of these is associated with the *Titanosarcollites* beds of this inlier, and the younger zone is found in shales associated with the *Lopharizpensis jamaicensis* beds (the oyster limestone). Only two species found in the oldest of the three zones are found in the middle zone, and the youngest and oldest zones share no species. Further, the middle and youngest zones share only three species. Apparently, after an ostracode fauna became established it would be destroyed by a volcanic episode and then the island repopulated from elsewhere in the region. Planktic microfossil data suggest that the three ostracode zones are within the nannofossil *Quadrum trilidum* Biochronozone, which is of late Campanian to early Maastrichtian age.

#### EFFECTS OF HURRICANE GILBERT ON THE JAMAICAN COAST WITH PARTICULAR REFERENCE TO DAMAGE AND RECOVERY OF BEACHES

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The eye of Hurricane Gilbert swept across central Jamaica from east to west on September 12, 1988. This track effectively divided the island into two with respect to damage in coastal areas, the more dangerous north-westerly quadrant of the storm impacting the east and north coasts while the southern coast was in a relatively sheltered position with respect to surge and storm wave effects. Initial post-storm damage inventory was attempted for beach areas by several groups. Along the north coast, impacts were highly variable, ranging from extensive erosion of some beaches and accretion on others, plus damage to coastal structures such as roads, seawalls and groins. Assessment of changes was hampered by two major problems: 1) the apparent absence of standardised recording and reporting techniques and 2) lack of systematic baseline beach observations against which quantitative measurements could be scaled. In addition, there was inadequate information on pre-storm deterioration of coastal infrastructure.

Total estimated insurance loss due to Hurricane Gilbert for private and public facilities islandwide was 50 billion \$Ja. However, of expenditure through the Ministry of Construction on post-storm rehabilitation of gullies, drains and rivers, the funds for restoration of coastal infrastructure formed only 3% of the total allocation of \$Ja 14m. Accurate figures for the cost of restoration on beaches are not available.

Many beaches that were severely damaged during the storm recovered rapidly within a short period of the event, and costs of hurricane damage must therefore be estimated in relation to likely post-storm beach recovery. We will provide an outline of essential baseline monitoring techniques for coastal areas, and demonstrate how such data can be used to assess the need for artificial post-storm beach recovery and for advising Government and private user groups, such as hoteliers, on the need for coastal defences and appropriate soft-substrate management procedures.

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The most cost-effective means of reducing the potential impact of natural hazards is by incorporating hazard considerations into the early stages of development planning. The most hazardous geologic phenomena are earthquakes, volcanic eruptions, and tsunamis. Two kinds of information are needed to evaluate earthquake threat to an area: 1) potential severity of an earthquake and 2) likelihood of a damaging earthquake occurring in that area during a particular timeframe. Information is presented for the former in terms of areas that experienced Modified Mercalli Index intensity values of VI or greater and for the latter in terms of percent of conditional probability for ten and 20 year periods. This information is presented at the level of provinces (or equivalent political subdivisions) for South America and Central America. Similar information is presented at the country level for the Caribbean in terms of estimated maximum magnitude  $M_s$  of 4 or greater and scaled likelihood of occurrence of a large earthquake in the near future. Comparable information on Mexico is presented in a different manner. For evaluating volcanic hazards, a list of all volcanoes that have erupted in Latin America and the Caribbean in the last 10,000 years is classified as to location; long- or short-term periodicity; maximum scale of eruption; eruptions that caused deaths or property damage; number of eruptions of each volcano and date of the latest eruption; and associated hazards--explosive eruptions, pyroclastic phenomena, lava flows, and lahars. For tsunamis, wave heights of 2-3m, 3-5m, and 5+m above normal caused by hypothetical earthquakes in seismic gaps on the west coast of South America are shown for population centers from Ecuador to Chile and information produced by another means is presented for Mexico to Colombia. The information presented should be sufficient for a planner conducting a preliminary regional survey to determine if earthquakes, volcanic eruptions, or tsunamis constitute a significant threat in the survey area.

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Four distinct patch reef assemblages have been identified in the back-reef areas of the Buccoo Reef Complex, Southwestern Tobago. This differentiation is based on ecology, associated sediment distribution, and their geographic location within the back-reef environment.

Algae - Porites assemblages are elongate to sub-circular in plan view, and dominated by algal-encrusted coral rubble, and minor clumps of Porites porites and Thalassia testudinum. Elongate-shaped Acropora assemblages are composed of thickets of Acropora cervicornis, with minor stands of A. prolifera and species of Siderastrea, Agaricia, Montastrea and Diploria. Acropora-Millepora assemblages which are elongate to sub-elliptical in shape, are compositionally similar to the Acropora assemblages, except for the introduction of extensive occurrences of the hydrozoan Millepora. A single occurrence of the elongate to tabular-shaped Montastrea assemblage is predominated by coral heads of Montastrea annularis.

Halimeda plates and mollusc grains are the dominant sediment particles associated with Algae - Porites assemblages. Fragments of coral and coralline - algae, along with Halimeda and mollusc particles in varying percentages, occur on the substrates of the Acropora, Acropora - Millepora, and Montastrea assemblages.

The patch reef assemblages recognized in Buccoo Reef, are ecologically similar to identified zones of coral communities on the fore-reef slopes of reef complexes. By a similar comparison, their different geographic locations within the back-reef environment are due to a combination of physical parameters, namely wave exposure, water circulation, water depth, turbidity and salinity.

#### EXPLOITATION OF THE MIDDLE MIOCENE OIL BEARING INTERMEDIATE HERRERA SANDSTONE RESERVOIRS IN A THRUST FAULTED AREA IN TRINIDAD, WEST INDIES

By

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The Herrera sands contain the major oil producing reservoirs of Miocene age in Trinidad's Southern Basin. They lie within the Upper Cipero shale formation in the Penal/Wilson, Barrackpore and Ortoire fields of South-Central Trinidad. These turbidites sands are found at three levels, the 'Overthrust', 'Intermediate' and 'Underthrust': each level separated by a major thrust fault, and associated with a complex structure of a strong overfold and recumbent syncline formed by major tectonic movement at the end of Middle Miocene time.

The Intermediate Herrera sands are confined to a long (17 miles) and narrow (2,000 feet) area trending NE-SW from the Penal/Wilson field to the Barrackpore Mandingo field. The sands are found at depths of 6,000 to 10,000 feet in a complex structure which plunges to the southwest and is cut by numerous extensional cross faults which form separate hydrocarbon pools. Exploitation of these pools commenced in 1946 and by December 31, 1988, the cumulative production totalled 18 million barrels of oil/condensate and 30 billion SCF of natural gas. Presently, these sands offer the best potential for continued exploitation of the undeveloped reserves in the area. Additional unrecovered proven reserves are 4.5 MMB oil/condensate and 4.5 BCF of natural gas. Potential reserves in undrilled prospective areas (845 acres) are estimated at 15 MMB oil/condensate and 15 BCF of natural gas.

This paper examines the major aspects of this Miocene play showing the structural and stratigraphic interpretations of the Intermediate Herrera sands and their associated production characteristics. Development trends of the fields are shown and an outline of future plans for exploitation of reserves remaining in the Intermediate Herrera sands is presented.

#### ENVIRONMENTAL IMPACTS AND CORAL DEGRADATION, BARBADOS COAST

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Not all is environmentally well in the Barbados coastal zone. The nearshore waters, subtidal reef coral substrate, beaches, backshore and inland zone are all a part of a dynamic interacting environmental system. Environmental deterioration has occurred and is accelerating with adverse effects especially on the west coast.

The intensively developed south and west coast beaches of Barbados have a general post-settlement and recent erosional history due to the degradation and destruction of beach vegetation and inshore fringing coral reefs. The south and west coasts were generally accretional prior to settlement of the island. Convergence of data collected during this study suggests that extensive shallow water coral mortality followed the clearing of the land for sugar cane monoculture. Torrential storm runoff, soil erosion and turbidity accompanying "The Great Hurricanes" may have resulted in the loss of live coral on the inshore fringing reefs and significant shore change.

Accelerated shallow and deeper water coral mortality on the south and west coasts during the past two decades appears to have been coincidental with increasing coastal urbanization and improvements of storm and wastewater drainage systems and introduction of coastal sewage outfalls. Superimposed on these factors are effluent disposal from rum plants, industrial outfalls, and the enrichment of the coastal groundwater circulation not only by wastewater disposal in the soil environment but also to a lesser extent by leaching of fertilizers from the inland canefields. Evidence of eutrophication (nutrient enrichment) in the coastal beach environment is widespread and includes green algal blooms, anaerobic sediments, foul odours, poor underwater visibility and the displacement of live coral on the shallow reefs by crustacean algae. Souvenir collectors, boat anchors, periodic dredging, and coastal structures are also factors in reduction of the living coral cover.

Long term protection of Barbados' leeward sandy beaches requires the improvement of water quality in the coastal zone and re-establishment of healthy coral communities. Short term structural beach protection measures will be effective only in the context of long term water quality improvement. Clean up of the coastal environment will make Barbados a more desirable tourist destination and protect its valuable beach resources and improve the quality of life for its residents.

# SEDIMENTOLOGY OF THE LATE PLEISTOCENE IRONSHORE FORMATION ON GRAND CAYMAN

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The Ironshore Formation on Grand Cayman comprises Facies A-G which were deposited in the Ironshore Lagoon. Facies A-F are temporal equivalents; Facies G is a later filling of the lagoon.

Facies A, restricted to the eastern end of the lagoon, consists of abundant bivalves in a matrix of moderately sorted carbonate silt and very fine grained sand. These allochems are predominantly cryptocrystalline grains (recrystallized skeletal grains), *Halimeda*, and benthic foraminifera. Facies B, deposited throughout most of the Ironshore Lagoon, consists of abundant bivalves in a matrix of poorly sorted carbonate sand and silt, composed predominantly of cryptocrystalline grains and *Halimeda*.

Facies C includes a series of patch reefs, which formed near the westward opening of the lagoon. These patch reefs, from 2-3 m to over 300 m in diameter, are dominated by *Montastrea*, *Diploria*, *Porites*, *Siderastrea*, and *Agarcia*. The larger patch reefs, which show a distinct zonation, have a higher diversity than the smaller patch reefs, which are commonly monospecific. Facies D, consisting of carbonate sands and silts, was deposited between the patch reefs.

Facies E comprises a diverse assemblage of corals, similar to those in the patch reefs, but also containing *Meandrina*, *Acropora*, *Pocillopora*, and *Dendrogyra*. These corals grew in a reef tract across the western edge of the lagoon, in a back reef environment. Facies F, which consists of well sorted skeletal sands or ooids, crosses Facies E, and is a series of channels through the reef tract.

Facies G consists of oolitic limestones that probably formed in a quiet water setting. This facies was the last filling of the lagoon and overlies Facies C, D and E. The oolitic limestones, with marine trace fossils, are found up to 4 m above present day sea level, indicating that sea level was at least 4 m above present day sea level during the late Pleistocene on Grand Cayman.

# POSICIÓN ESTRATIGRÁFICA DE LOS RUDISTAS DE CAMAGÜEY, CUBA

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Los yacimientos de rudistas del territorio camagüeyano se encuentran en dos paleoambientes distintos: como parte de un banco carbonatado perteneciente a la margen continental mesozoica de Las Bahamas, y como intercalaciones de calizas en una secuencia efusivo-vulcanógeno-sedimentaria propia de un antiguo archipiélago volcánico.

En el banco carbonatado hay un biostroma con *Biradiolites moretownensis* de edad Campaniano a Maestrichtiano, así como varios horizontes de calciruditas con fragmentos de radiolíticos de mayor antigüedad.

La secuencia efusivo-vulcanógeno-sedimentaria cretácica incluye lavas, tobas, tufitas y varios horizontes de calizas biógenas con rudistas. El nivel más antiguo es del Albiano e incluye *Sabinia* sp., *Tepeyacia corrugata* e *Ichthyosarcoceras* sp. Le sigue probablemente un horizonte con *Durania curasavica*, *D. lopeztrigoi*, *Vaccinites magillavri*, *Torreites tschoppi* y *Præbarrettia coralli*. La ausencia de foraminíferos orbitoidales hace suponer que se trata de un horizonte del Coniaciano ? Al Santoniano. Otro nivel con rudistas incluye *Barrettia moniliifera*, *Parastroma sanchezi*, *Antilocaprina acutodentata*, *Bifidolites acuticostatus*, *Lapeirousia nicholasi* y los foraminíferos orbitoidales *Pseudorbitoides* sp. y *Sulcoperculina* sp. Esta asociación puede datarse del Campaniano, pero quizás se extienda al Santoniano.

Discordante sobre la anterior secuencia se encuentra un conglomerado y potente banco de calizas del Campaniano tardío al Maestrichtiano con *Biradiolites moretownensis*, *Titanosarcoceras giganteus*, *Mitrocoprina tschoppi*, *Antilocaprina annulata*, *Bournonia thiadensis*, *Præbarrettia sparsillata*, *Bournonia cancellata*, *Parastroma quitarti* y foraminíferos orbitoidales.

# VEGETATIVE AND GEOMORPHIC PATTERNS IN RELATION TO MASS WASTING IN A MONTANE-TROPICAL FOREST, PUERTO RICO

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An analysis of woody-species distribution was related to aspect, slope declivity, elevation, and landslide features. The study area is located on mountainous slopes of the Caribbean National Forest, Puerto Rico, where landsliding may be the most important surficial-geomorphic agent. Rainfall in excess of 3000 mm per year facilitates the development of diorite derived, saprolite soils, up to 20 m thick, whose weathering profiles strongly affect modes of slope failure. Forty-nine canopy-tree species were identified along transects ranging in elevation from 150 to 800 meters. No significant relations were observed between vegetation pattern and aspect. Vegetation patterns are most affected by slope declivity and elevation; vegetal variation with elevation is well documented and only discussed here to avoid spurious geomorphic interpretation. Mountain palm (*Pretoea montana*) is strongly associated with concave-upward slopes, having the highest importance values (relative frequency, basal area, and density) in 88 percent of cove transects; it frequently occurs in water-logged soils and on saturated landslide-disturbed surfaces. Convex-upward and intermediate linear slopes tend to have fewer palms and support *Micropholis* and *Cyrilla*, at higher elevations (600 - 800 m) where landsliding is most common. *Cyrilla*, and certain *Micropholis* and *Clusia* species are largely restricted to ridge and convex-upward slopes and appear to reflect long periods of slope stability. Thus, most landslide activity may occur in concave-upward slopes. Microtopographic features associated with rotational slumps, debris avalanches, and earthflows affect large-scale species patterns; tree ferns, *Cecropia*, and *Didymopanax* tend to dominate during the early stages of landslide regrowth. Trends of basal area and stem density may reflect time since last landslide disturbance and relative stability; basal areas up to 30,170 cm<sup>2</sup>/400 m<sup>2</sup> occur on stable, *Cyrilla* dominated, linear and convex-upward slopes, and may be as low as 9,776 cm<sup>2</sup>/400 m<sup>2</sup> on unstable, *Pretoea* dominated, concave-upward slopes. Vegetation analyses in combination with detailed geomorphic and soil-mechanics analyses may provide a valuable tool in identifying areas of varying landslide susceptibility.

# RECONSTRUCCIÓN PALEOGEOLÓGICA DEL ARCHIPIÉLAGO VOLCÁNICO PALEOGENICO TEMPRANO EN CUBA

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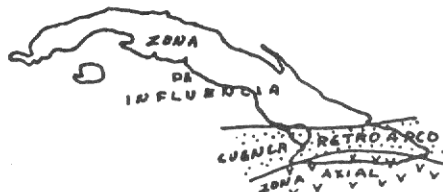
En el territorio de Cuba se encuentran rocas magmáticas del Paleoceno al Eoceno Superior temprano que se pueden relacionar al arco volcánico "Los Caímanes", que se extendía desde el elevado de Nicaragua-Dorsal de los Caímanes hasta las Antillas Mayores y la Cresta de Aves.

Entre los límites de Cuba se reconocen tres elementos paleogeológicos propios de dicho arco: La zona axial del arco, la cuenca de retroarco, y la zona de influencia del arco. Ellas representan la atenuación de la actividad magmática efusiva en dirección a Cuba-Bahamas.

La zona axial del arco está presente en la Sierra Maestra y se caracteriza por la abundancia de rocas piroclásticas, lavas basálticas hasta riolíticas, y cuerpos subvolcánicos de la misma composición. También están desarrollados los cuerpos apicales de un plutón de dioritas, granodioritas, granitos, plagiogranitos y otras rocas.

La cuenca de retroarco se extiende al flanco N de la Sierra Maestra, las alturas de Moa, Cristal, Baracoa, y los valles del Cauto, Nipe y Guantánamo. Se caracteriza por la abundancia de piroclásticas medio-ácidas que se intercalan con clásticas polimícticas procedentes del N y V. Son escasos los cuerpos efusivos y subvolcánicos.

La zona de influencia del arco se extiende al resto de Cuba. Se manifiesta por las intercalaciones de tufitas de ceniza entre los sedimentos clásticos y carbonatados del Paleoceno al Eoceno Medio. Esto indica que las erupciones explosivas fueron muy frecuentes en el arco.



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L'étude comparée des schémas d'évolution de la Basse-Terre de Guadeloupe et de l'île de Montserrat, sur la base de critères pétrographiques et d'arguments géochronologiques, montre une similitude de l'évolution volcanologique de ces îles.

On distingue dans les deux cas, trois grands ensembles correspondant aux arrivées successives de trois masses magmatiques majeures. Les évolutions se sont effectuées globalement du Nord vers le Sud le long d'axes de distension N-S.

Les activités volcaniques actuelles se localisent au Sud (Soufrières actives) et à l'Ouest (champs géothermiques) pour les deux îles et le long d'axes structuraux essentiellement orientés NE-SW et NW-SE.



Localisation schématique des trois ensembles (1 à 3) volcaniques en Guadeloupe (à gauche) et Montserrat (à droite)

# ETUDE DES SOLS LIES AU VOLCANISME ACTIF DES SOUFRIERES DE GUADELOUPE ET DE MONTERRAT

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La comparaison des sols étudiés sur les appareils volcaniques de la Soufrière de Guadeloupe et de la Soufrière de Galway's à Montserrat, a montré que sous climat tropical et sur matériel andésitique peuvent se rencontrer des sols présentant des stades d'évolution très différents. Les sols observés à la Guadeloupe sur des matériaux jeunes, sont des andosols différenciés riches en substances amorphes (allophanes), alors qu'à Montserrat se rencontrent plutôt des sols peu évolués sans présence de substances amorphes et des sols bruns entrophes tropicaux sur des matériaux anciens.

Ces différences peuvent s'expliquer par :

- une pluviométrie plus importante à la Guadeloupe qu'à Montserrat,
- la plus grande perméabilité des matériaux volcaniques de la Guadeloupe,
- une vitesse et une intensité d'évolution plus importante en Guadeloupe qu'à Montserrat, du fait de la présence à la Soufrière de Guadeloupe de produits ayant favorisé la séquence évolutive andosolique, tels que les cendres, les lapilli et les ponces très perméables, les matériaux argileux hydrothermaux hérités, les solutions acides riches en cations, en silice et en aluminium.

# LITHOLOGIES AND STRATIGRAPHY OF THE PERALVILLO FORMATION IN THE CERRO DE MAIMON AREA, CENTRAL DOMINICAN REPUBLIC

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Preliminary information has been obtained from field observations and drill cores in the Cerro de Maimon area on the Peralvillo Formation which extends as a 0.5 to 2 km wide belt between the El Caribe sepetized peridotite and the Maimon (schist) Formation to the north, within the Median Belt of the Cordillera Central. The base above the peridotite consists of mafic volcanic rocks intruded by mafic intrusive bodies of variable grain size. This mafic sequence is presumably equivalent to that seen at Sabana Potrero to the east and is overlain by about 200 m of fine mafic tuffs grading into cherty tuffaceous sedimentary rocks. The sedimentary sequence dips at about 45° to the south and is overlain by mafic volcanic rocks consisting mainly of volcanoclastic tuffs and breccias but including flows of amygdaloidal basalt. Drill cores through the upper part of the section below the Maimon contact intersect brecciated recrystallized limestones with carbonaceous horizons and graded felspar-quartz-lithic sandstones and siltstones of definite sedimentary origin. Felsic volcanic rocks (dacites) also occur in the upper part of the section interspersed with the mafic volcanoclastics.

The relationship between the limestones and other calcareous units in the drill cores and the Los Banitos limestone of apparent Early Eocene age mapped by Bowin (1966) has yet to be determined. The contact with the Maimon schists is faulted, and is characterized in drill cores by a 5 - 10 m thick gauge zone of predominantly sheared chloritized rock.

# CRETACEOUS RUDISTID PALEOBIOGEOGRAPHY OF THE CARIBBEAN PROVINCE

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Late Jurassic-Early Cretaceous opening of the Caribbean Basin produced a new western arm of the Tropical Tethyan Sea which ultimately connected to the Pacific Ocean to form a circum-equatorial Tropical seaway. Climate models suggest that during eustatic highstand and global warming periods, with elevated atmospheric CO<sub>2</sub>, the Tropics were possibly divided into three climate/paleobiogeographic zones; a central zone of higher than normal temperature and salinity termed "Supertethys", flanked by northern and southern Tethyan zones similar to the modern Tropics. The development and disappearance of "Supertethys" strongly influenced paleobiogeographic evolution of Caribbean reef ecosystems. Late Jurassic and earliest Cretaceous coral-algal dominated reefs and associated communities were primarily composed of European lineages, so were the rudistid bivalves that moved into reef niches during the Barremian-Aptian. Lack of Lower Cretaceous provincialism among Caribbean reefs reflected relatively short planktotrophic larval drift distances across the spreading Atlantic ocean. Beginning in the Albian and extending throughout the Maastrichtian, Atlantic spreading exceeded larval drift distances for many coral and rudistid lineages, initiating Caribbean provincialism. Percentages of endemic taxa expanded from subprovincial grade during the middle Cretaceous to provincial grade during the late Cretaceous. Diversity, endemism and the distinctness of Caribbean paleobiogeographic subdivisions diminished during Turonian through Santonian time as a result of volcanism. Campanian through Maastrichtian radiation of rudistids gave rise to significant endemism, especially in central to southern Mexico, Jamaica, Cuba and the Greater Antilles, reflecting continued opening of the Caribbean and relative isolation of northern and possibly southern Tethyan margins. Rudistid reef ecosystems collapsed near the Middle-Late Maastrichtian boundary, at a peak in their evolutionary and paleobiogeographic radiation. Rapid cooling and collapse of the "Supertethyan" zone are proposed causes.

# TITLE: PETROLEUM GEOLOGY OF THE WOODBOURNE OIL FIELDS

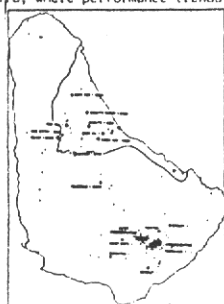
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The Woodbourne Oilfield consists of two distinct areas of production: Central Woodbourne and West Woodbourne. The two fields are divided by a minimum of six over thrust fault segments striking north-east south-west as seen in the surface exposures of the Scotland District.

Oil and Gas Production is from Eocene and Miocene sand stones of the Scotland formation. These reservoirs are heavily interbedded with shale in upward coarsening turbiditic sequences that form complicated multi-level hydrocarbon accumulations. Huge variations in thickness, sand body orientation and geometry, reservoir quality and hydrocarbon type are attributed to the complicated depositional and structural history of the Scotland formation within the Barbados accretionary prism.

The most productive sandstone body [Basal Scotland Series] is postulated as a multistage channel deposit near the distal portion of a submarine fan that has been preserved and rests unconformably on a pelagic shale sequence. A depositional model allowing progressive overlap of distal, intermediate and proximal slope sediments within one vertical sequence, explains vertical variation and many hydrodynamically separated oil and gas reservoirs, where performance trends and reservoir continuity are different between the three main reservoir groups: The Basal Scotlands, Upper Scotlands and Intermediate Unit.

Highly productive wells within the main channel correlate with low sand/shale ratios and structurally high positions. Conversely, marginal producers show poor reservoir communication and quality coupled with a low structural position. Cross folding is seen at the main structural element in influencing entrapment.



## GEOLOGICAL EVOLUTION OF THE OLIGOCENE-MIOCENE BLUFF FORMATION, GRAND CAYMAN

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The core of Grand Cayman, like the other Cayman Islands, is formed of dolostone which belongs to the Bluff Formation. On Grand Cayman a major disconformity divides it into the lower Cayman Member and the upper Pedro Castle Member.

The Cayman Member is formed of hard, massive, white, microcrystalline dolostone that contains abundant massive and branching corals, bivalves, gastropods, foraminifera, and red algae. This member has high porosity because of (1) leaching of fossils that originally had aragonitic skeletons and (2) dissolution of bedrock associated with karst development. Many of the fossil molds and caves have been partly or totally filled with caymanite (red, white and black), fossiliferous grainstone, terra rossa, and/or flowstone.

The disconformity separating the Cayman and Pedro Castle members is a distinct planar surface that was bored by sponges, worms, and bivalves and locally encrusted by red algae. Sedimentological and diagenetic evidence suggests that the Cayman Member was subaerially exposed and subjected to karst development prior to deposition of the Pedro Castle Member. Corals in the upper part of the Cayman Member suggest that it is of late Oligocene age whereas those in the Pedro Castle Member suggest a middle Miocene age.

The Pedro Castle Member is formed of relatively soft cream to white coloured dolostones that are characterized by abundant foraminifera, rhodolites, and free-living corals. Although porosity is high because of leaching of the corals there is no evidence of dissolution associated with karst development. Only small amounts of white caymanite are present in a few of the coral molds. Although terra rossa occurs in some cavities no fossiliferous grainstone or flowstone has been found.

Petrographic and geochemical evidence suggests that the original limestones of the Bluff Formation underwent only one phase of pervasive dolomitization.  $^{87}\text{Sr}/^{86}\text{Sr}$  isotope ratios suggest that the dolomitization occurred approximately 2 million years ago.

## DISPERSION OF CRETACEOUS TO RECENT VOLCANIC TERRANES IN THE NORTHEAST CARIBBEAN

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Volcanic rocks of the northeastern Caribbean are divided into 6 volcano-stratigraphic groups. The volcanic rock groups are defined as follows: the Basal Group, Late Jurassic-Early Cretaceous oceanic and island arc rocks; Arc 1 Group, middle Cretaceous island arc rocks; Arc 2 Group, Late Cretaceous-Early Tertiary island arc rocks; Arc 3 Group, middle Eocene-early Miocene island arc rocks; Arc 4 Group, Pliocene-Quaternary island arc rocks; Caribbean Group, Cretaceous-Tertiary oceanic igneous and sedimentary rocks. The distribution of these rock groups within and between islands allows for terrane distinction and reconstruction. The terrane reconstruction suggests that Puerto Rico lay south of Hispaniola and that the northern Lesser Antilles lay south of Virgin Islands in the late Eocene. Dispersion of the arc terranes occurred first between Hispaniola and Puerto Rico. Some 300-400km of strike slip translation occurred between these two islands in the late Eocene-early Oligocene. Strike slip motion of 100-150km between the Virgin Islands and the Lesser Antilles occurred during middle Oligocene-middle Miocene. Since middle Miocene about 300km of translation carried northern Hispaniola from north of Puerto Rico and the Virgin Islands to its present location. The present model of terrane dispersion is generally consistent with spreading rates in the Cayman Trough and the location of Tertiary basins in the northeast Caribbean.

## Structural Geology of the West End of St. Croix, U.S.V.I.

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Analysis of the structural features in late Cretaceous interbedded volcanoclastic sandstones and mudstones on the west end of St. Croix, U.S.V.I., indicates that the initial phase of tectonic activity produced major and minor folds. Such folds are folded about axes which plunge moderately NE-E. Minor fold axial planes and axial plane cleavage strike N50W on the average and dip moderately to the SW. The cleavage varies up to 30° from the average strike, however, within domains only a few feet in size. Several observations suggest that initial folding began before lithification. Mud appears to have flowed during folding producing mud "phacoliths" near hinges of larger minor folds. Wackes and sands also show signs of some flow during folding. Arenite beds intrude under lying mudstones by rounded load casts. The load casts are commonly elongate and define lineations on the base of arenite beds. Load cast lineations parallel fold axes of the initial phase of folding, suggesting that loading and folding were contemporaneous. This phase of deformation is correlated with Speed's (1974) east end-tectonic phase 2, which produced open to tight, mainly asymmetric, minor and major folds of bedding possessing axial plane cleavage.

Later-phase tectonic activity produced kinks of bedding and cleavage, chevron folds of bedding and cleavage, and faults with assorted offsets. No evidence of flow during this later phase folding was observed. Kinks are similar in orientation to some faults, and some kinks and chevron folds die out into faults. Some later phase folds and faults may have been produced by the same kinematic event. Average axial plane cleavage attitude is constant over all areas observed indicating no later folding on scales greater than outcrop in size. Many faults strike ENE-WNW with left lateral offsets. Perhaps they are part of the distributed shear related to the Caribbean-North American plate boundary. The present analysis contradicts Whetten's (1966) structural interpretation of the west end of St. Croix wherein E-W axial plane folds have been cross folded by folds with N-S axial planes.



# ECOLOGICAL EVOLUTION OF CRETACEOUS CARIBBEAN REEFS

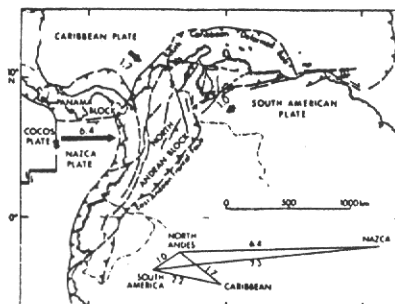
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During the Cretaceous, Caribbean reefs/frameworks underwent a dramatic evolution in size, distribution, and ecologic composition. Small Lower Cretaceous bioherms and biostromes were dominated by low diversity coral-algal communities; rudistid bivalves occupied lagoonal and inner platform environments as thin lenticular biostromes of recumbent *Regulinitidae*, *Caprotinidae* and early *Caprinidae* in paucispecific communities without persistent succession. Middle Cretaceous rudistids rapidly replaced coral-algal communities in prime reef habitats throughout the central Caribbean Tethys. Radiolitidae and *Caprinidae* dominated loosely-constructed frameworks, shelf margin bafflestone banks, and densely-packed inner platform bioherms with simple two to four stage successions. In northern Tethyan habitats, coral-algal dominated communities persisted in early reef development but were succeeded by caprinid/regulinitid-dominated communities in latter stages. These regional differences in succession suggest both broad scale competitive displacement of corals by evolutionarily convergent rudistids, and environmental stress gradients connected with emergence of "Supertethys" (higher temperature and salinity than in normal Tropical settings) favoring more eurythermal rudistid bivalves over coral-algal community elements. Upper Cretaceous platform reefs/frameworks throughout Tethys were strongly dominated by rudistids in all biofacies; corals diversified in secondary habitats. Complex lateral and vertical ecological successions characterized Upper Cretaceous frameworks. Primitive recumbent *Caprinidae* formed pioneer communities, small erect to recumbent *Radiolitidae* formed early successor communities, and erect, densely packed (pseudocolumnal) *Radiolitidae* and *Hippuritidae* formed climax communities in shelf margin and platform reefs. Specially adapted rudistids dominated small biostromal, biohermal, and bafflestone frameworks as these bivalves extensively niche-partitioned latest Cretaceous carbonate and siliciclastic platforms. Epi- and endobiont microcommunities on rudistid framework builders gradually increased in numbers, diversity and levels of microsuccession through the Cretaceous. Intra- and end-Cretaceous extinctions of rudistids decimated the ecologic structure of platform reef/framework communities at peaks in their evolution and may have been related to the breakup and disappearance of the "Supertethyan" zone associated with global cooling.

# MICROPLATE TECTONICS OF THE SOUTHWESTERN CARIBBEAN MARGIN

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Since Middle Cretaceous time, two major oceanic island arc terranes have been accreted to the South American continental margin. Structural field studies and gravity and seismic refraction models suggest that during Late Cretaceous time, the West Andean arc was obducted eastward onto the continental margin. This obduction may have been related to the eastward movement of the Aves Ridge past the northern Andes. During Miocene time the Panama arc collided with the West Andes. The Panama arc terrane is defined by exotic Paleocene foraminiferal assemblages. Recently discovered westward verging folding and thrusting between the Western and Central Andes may be associated with the Panama collision. Continued convergence of the Nazca, Caribbean, and South American plates is being accommodated by deformation of the Panama and North Andean microplates (figure). Active folding and thrusting on the southwest Caribbean margin and Wadati-Benioff zones suggest slow amagmatic subduction of Caribbean crust beneath Panama and the North Andes. Active tectonic strain in the southwestern Caribbean is being monitored by the Central and South America (CASA) satellite GPS geodetic network.



# COMPOSITE ASSEMBLAGE BIOSTRATIGRAPHY OF THE CARIBBEAN PROVINCE

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Calcareous and siliceous microplankton, ammonites and inoceramid bivalves (in siliciclastic facies), rudistid bivalves, echinoids, nerineid and actaeonellid gastropods, and larger foraminifera (in carbonate platform facies) have been used to construct independent systems of biozonation and correlation in the Tropical Caribbean Province (Tethys). These systems have been limited in resolution by episodic preservation of component taxa, incomplete systematic studies, temporal and spatial mixing of distinct siliciclastic and carbonate biofacies resulting in a lack of stratigraphic continuity of lineages, and where lineages are well known, by the maximum evolutionary rate of component taxa. A new Cretaceous biostratigraphy for the Caribbean Province has been constructed by: (1) more detailed taxonomic studies of certain common molluscan lineages (*Actaeonellidae*, *Inoceramidae*, *Hippuritidae*, *Pectinidae* and *Ostreidae*), yielding greater refinement of species ranges; (2) revised biostratigraphic zonations among planktonic foraminifera, nannoplankton, radiolarians and dinoflagellates originally proposed during the last decade; (3) integration of all biostratigraphically useful taxa within major facies and regions of the Caribbean Province using composite assemblage biozone methodology; and (4) integration of assemblage biozone data from different areas/facies of the Caribbean Province utilizing graphic correlation techniques. This has resulted in an increase in refinement of biozonation for the Caribbean Cretaceous, and more precise correlation to the highly refined biostratigraphic systems of the Western Interior and Gulf Coast regions of North America. Further refinement of Caribbean biozonations will depend upon detailed lineage studies of new groups of marine taxa, especially among Mollusca.

The Petrogenesis of the Washikemba Fm:  
a primitive island-arc volcanic sequence

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The Washikemba Formation of Bonaire (late Albian to Coniacian) is an over 5 thick submarine succession of lavas, shallow intrusions and subaqueous pyroclastic flows alternating with pelagic sediments. It is estimated that the sequence was formed at a waterdepth of 3500m near the base and 1000m near the top.

The volcanics form a bimodal suite composed of andesites and "rhyolites". Based on their field occurrences the "rhyolites" can be divided in low-viscosity (LVR) and high-viscosity (HVR) types. All rocks have been weathered and altered to low-temperature mineral assemblages. However both unaltered examples of the andesites and "rhyolites" are found.

The HVR have Hyg (Hygromagmatophile elements) patterns roughly similar to those of the andesites but two to three times higher in absolute abundances. The patterns indicate derivation of the HVR from the andesites by fractional crystallization of plagioclase, apatite and magnetite. The LVR have Hyg elemental patterns scarcely higher than those of the andesites. Unaltered LVR samples indicate an original SiO<sub>2</sub> concentration of about 65 wt % for the LVR. Hyg elemental abundances for the altered and unaltered LVR samples are similar. This rules out derivation of the LVR from the andesites by fractional crystallization of plagioclase, apatite and magnetite. The parental magma(s) of the LVR should have very low Hyg elemental abundances. Basalts with low Hyg elemental abundances indicative for such magmas, do occur in the Washikemba Fm but are very scarce.

# DEPOSITIONAL HISTORY AND GEOCHEMISTRY OF THE MID-CRETACEOUS OCEANIC PLATEAUS

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The Mid- to Late Cretaceous oceanic plateaus in the Western Pacific, Indian Ocean and Caribbean represent a major and enigmatic process of formation of oceanic crust. Oceanic plateaus differ from normal oceanic crust in terms of their thickness, extent of flows and geochemistry. Detailed stratigraphy of now on land exposed equivalents (the Curacao and Aruba lava formations) of the oceanic plateaus are here discussed. Both formations consist entirely of basaltic flows, hyaloclastites and shallow-seated sills. Piling up of the basaltic sequences occurred during a short timespan. The basal part of the Curacao lava formation (>5000 m thick) was formed at a waterdepth of about 5 km and the presence of lapilli tufts, well sorted conglomerates and a paleosol in the Aruba lava formation (>3000m thick) indicate subaerial volcanism. Trace element characteristics of the Curacao and Aruba lava formations resemble N-type MORB without the Nb, Ta, and LREE relative to chondrites. Nd and Sr systematics indicate that these basalities have oceanic island affinities with radiogenic isotope characteristics similar to the Easter and Galapagos Island hotspots. Both formations are similar in trace elements and isotope ratios as the majority of the Western Pacific and Caribbean oceanic plateaus.

The narrow range in trace element composition and isotope systematics of all these oceanic plateaus indicate an episode of increased global volcanism in Mid to Late Cretaceous times

# REVIEW OF THE UPPER CRETACEOUS ORBITOID LARGER FORAMINIFERA FROM JAMAICA, W.I.

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Larger foraminifera are known from most of the Cretaceous inliers in Jamaica. In the western Cretaceous Green Island and Grange inliers, the Barrellia Limestone is characterized by extremely rich populations of *Pseudobulimina trechmanni*. The small Green Island Inlier is the type-locality of *P. trechmanni*, but in addition, contains *Radiolobulimina pacinatus* a form regarded to belong to an evolutionary lineage diverged from the *Pseudobulimina*-lineage. The revised age of the unit is Late Middle Campanian on the basis of nannoplankton.

In the Sunderland Inlier, the shales of the Sunderland Formation comprise a horizon which contains the evolutionarily less advanced *Pseudobulimina chubbii*. The overlying Stapleton Limestone contains an abundance of specimens identified as *P. trechmanni*. Rich populations of *Radiolobulimina pacinatus* have been described from beds both underlying and overlying the Stapleton Limestone. Based on nannofossils from the Sunderland Inlier, *P. chubbii* is now regarded as of approximately Middle Early Campanian age (Nannofossil zone 19a), *P. trechmanni* of Late Middle Campanian age (Nannofossil Zone 21b-21c), while *P. pacinatus* may range from Late Middle Campanian to possibly Early Late Campanian (Nannofossil Zone 21b-22a).

In the Central Inlier, marls, marly clays and rubbly limestones characterized by a foraminiferal assemblage comprising abundant *Kathina*, *Sulcoperculina*, *Orbuloides*, *Vaughanina* and minor *Asterorbis*. Preliminary results of statistical studies on the arrangement of neponic chambers in *Vaughanina* reveal that the forms are identical to *V. cubensis* PALMER. The sequence is succeeded by hard brown limestone with predominantly *Sulcoperculina* and *Chubbina cardenasensis*. Throughout the sections the rudists *Titanosarcollites*, *Anillocaprina chiapasella* and *Biradiolites jamaicensis* are common. The age of the sequence is now considered to range from possibly Late Campanian to Early Maastrichtian.

Two limestone horizons in the Blue Mountain Inlier contain larger foraminiferal assemblages which are directly correlatable with the Barrellia Limestone unit (or Stapleton Limestone) from the Green Island-, Grange- and Sunderland inliers, and with the Titanosarcollites horizons from the Central Inlier. The oldest unit is the Back Rio Grande Limestone which is characterized by an abundance of *Pseudobulimina trechmanni* and *Sulcoperculina*. The fauna occurs in a soft tuffaceous horizon at the very top of 7 m thick sequence of reef-rubbly beds with *Barrellia monillifera*. *P. trechmanni* from the Back Rio Grande shows an evolutionary stage of the juvenum identical to that in forms of Green Island, and a similar Late Middle Campanian age is suggested. The Rio Grande Limestone is an approximately 80 m thick calcarenitic to rubbly bioclastic limestone unit in which spectacular reefs of *Diatenella morataownensis*, various species of *Titanosarcollites* and radiolites occur in specific beds in the succession. Larger foraminifera comprise an assemblage of abundant *Sulcoperculina*, *Orbuloides*, *Vaughanina*, *Vaughanina* and to lesser extent *Pseudobulimina*. In all the occurrences *Pseudobulimina* is regarded to be represented by its species *P. pulianii*, which may point to a Maastrichtian age of the Rio Grande Limestone.

# Nd-isotopes of authigenic sediments as tracers for the Plate-Tectonic reconstruction of the Caribbean Plate

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All recent Plate-Tectonic reconstructions for the Caribbean assume that the Caribbean Plate did not form in the present gap between North and South America but rather is a detached part of the Parallon Plate

One way to support this fundamental assumption is to look at the Nd isotopes of authigenic sediments (Cherts, limestones and fish bones). Recent work has shown that Nd isotopic ratios of authigenic sediments from the Pacific and Atlantic are different. This difference in Nd isotopes started at the opening of the Atlantic. It is therefore proposed to measure the Nd isotopic composition of authigenic sediments in a number of time slices to see the change from Pacific towards Atlantic (or specific Caribbean) values. Moreover do the changes in Nd isotopes correspond with major changes in the Plate Tectonic configuration of the Caribbean Plate?

A Pacific origin for the Caribbean Plate has also important consequences for the Cretaceous Tertiary Boundary (KTB). Because of the continuous subduction of the Pacific Plate under the N/S American Continent, little is known about the KTB in the Eastern Pacific. The Caribbean Plate is possibly the only way to obtain information about, for instance, fluxes and integrated amount of Iridium, distribution of shocked minerals and K/T spherules, and eventual amount and fluxes of volcanic material in the Eastern Pacific.

To achieve the above objectives we propose to drill a complete section (double HPC/XCB/RCB) through the sedimentary cover, possibly in a number of short overlapping holes in the Venezuelan and/or Colombian basins above B". Basement drilling in these sites can further be used to identify the age and nature of the B" basaltic basement.

# THE SEDIMENTOLOGY AND PATROLOGY OF THE HERRERA SANDSTONES OF TRINIDAD W.I.

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Sedimentological and petrological examination of the Herrera sandstones of Trinidad show that these sand bodies were deposited from turbidity currents and are thus turbidites. They were sourced from the North or North West and occur as a series of small turbidite fans (a few kilometers in diameter) trending South West to North East.

The rocks are mostly lith-arenite with occasional quartz-arenite. The principal constituents are quartz, chert, lithic fragments and calcite. The principal accessories are feldspars and glauconite. The rocks are mineralogically immature. Porosity ranges from 0% to 20%. Clasticity index ranges from 0.1 mm to 1.2 mm. Generally the rocks are grain supported, matrix support being very rare.

The rocks have a complex diagenetic history with at least four phases of mineral growth or alteration. There were at least two invasive fluid phases, an earlier acidic phase which led to quartz growth and a later basic phase which led to calcite growth and porosity occlusion.

## COAL IN THE CARIBBEAN REGION

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Coals have been known in the Caribbean Region since 1850, or earlier, and attempts at recovery and utilization began shortly thereafter. Only in Colombia and Venezuela has coal ever been an important part of the nation's energy program. In most of the other nations of the region, the indigenous coal has never been mined to any extent. With increased energy demand, the traditional energy sources such as firewood and wood charcoal, have been replaced, in part, by imported petroleum products. Alternative indigenous sources of energy, such as coal and peat, deserve consideration and investigation.

An extensive literature search provided data for more than 235 locations where coal is known or reported to occur in the Caribbean Region. Most of these locations are in northern South America (108) and Central America (92) with the remainder (37) scattered through the Antillean island nations.

The reported coal locations in the northern part of South America are well explored compared to the coal areas of Central America and the Antillean islands. This is indicated by the distribution of the estimated identified-hypothetical coal resource potential of the region. Of the estimated total of about 11 billion tons, about 10.9 billion are in Colombia, Venezuela and Trinidad, about 350 million tons are in Central America and less than 160 million tons in the Antilles. It must be emphasized that the coal resource data in Central America and the Antilles are incomplete and both the geologic framework and coal quality information are inadequate for a definitive resource assessment in those areas. The required modification of the cited estimates awaits detailed exploration studies.

The 19° Fault, the Mona Canyon Graben, and the Neotectonics of the Puerto Rico Trench

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The South Somana Bay and Septentrional fault zones of northern Hispaniola can be traced offshore to the east where they are coincident with the Puerto Rico scarp. The Puerto Rico scarp extends to the east, bending around the northwest-trending Main Ridge of the Puerto Rico trench area. The Somana/Septentrional fault zone and its extension as the Puerto Rico scarp is here named the 19° fault, because of its latitudinal position. The fault was previously recognized as one that separates a blueschist terrane from an arc terrane. Motion on the fault zone is problematic; most workers in northern Hispaniola insist that the fault is left-lateral. However, the Mona Canyon, a Plio-Pleistocene graben, crosses the 19° fault, yet is only vertically offset, not laterally, indicating only down-to-the-north motion on the fault. Interestingly, the Mona Canyon graben changes direction across the fault, from north-trending south of the fault, to northwest-trending north of the fault. OLORIA studies of the Puerto Rico trench to the north of the fault by the U.S. Geological Survey indicate the presence of linear features interpreted to represent strike-slip faults. It is possible that the 19° fault is presently a normal fault near and to the east of the Mona Canyon, and that left-lateral shear is distributed between the fault and the trench, resulting in the rotation of the Mona Canyon graben without appreciable offset. Similarly, the northeast-trending Anomalous Block to the east of the Mona Canyon may have been or originally an east-west trending feature. Although the 19° fault east of the Mona Canyon is now a dominantly normal fault, in the past it exhibited strike-slip motion, as indicated by the juxtaposition of different terranes across the fault. The fault makes a releasing bend around the Main Ridge, and basins to the west of the Main Ridge may represent pull-apart or fault-divergence basins, and not true trench-slope basins as was previously proposed. These studies indicate that the Puerto Rico trench is a much more complicated feature than previously thought, and that more neotectonic studies are needed to further resolve the evolution of the region since the Miocene.

## EXTENSIONAL ALLOCHTHON IN THE MONA PASSAGE

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Active normal faults are widespread in the Mona Passage, as seen from an abundance of seismic reflection records on the eastern (Puerto Rican) part of the passage. Normal faults have arcuate shapes with scarp lengths up to 10's of kms, and rotation accompanies deformation in most cases. Faults with greatest displacement are along the Desecheo Escarpment, and the southern part of the Mona Canyon. Displacement seems to be consistently north-south. Maximum vertical and horizontal offsets are several kms. Age of faulting is probably Pliocene to Now, as evidenced from dredge haul data and information from submersibles. The zone of normal faulting can be traced eastward, onto Puerto Rico, where it extends from Aguadilla to approximately Ponce. The extension of the normal fault zone to the west is uncertain, owing to limited data, but may include the Yuma basin, or extend south of the Yuma basin. I propose, based on balanced cross-section constructions, that the normal faults lie above a decollement at approximately 6 kms depth, defining an extensional allochthon. This extensional allochthon toes into the Muertos Trough. The presence of this extensional allochthon helps explain some of the tectonic, seismic and geologic diversity of the eastern Greater Antilles. Another extensional allochthon(s) may be present south of eastern Puerto Rico, in the Whiting basin.

## SEDIMENT TRANSPORT ALONG THE BARBADOS COAST

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The littoral drift systems of the Barbados south coast and west coast are "pulses" driven. Large swells and tropical storms mechanically erode the reef system and also resuspend the biologically eroded reef sediments. Shoreline-refracted storm swell transports these sediments into the nearshore zone. Major sand influxes are cyclical with periods of a decade or more. On the west coast, south-westerly swell opposes northern swell "pulses" of littoral drift. On the south coast, littoral and nearshore drift is generally to the west but local beach cell reversals occur.

Very angular, clear quartz found within the fine sand fraction of the east coast carbonate sands serves as a unique tracer indicating coastal counter-clockwise sediment transport. Transport occurs from the east coast around the northern tip of the island with gradual southerly fall off in abundance downdrift along the west coast.

Size analysis characteristics reinforce the southerly west coast transport interpretation and are suggestive of pulses. Along the southwest coast, relict southeasterly transport paths are indicated. Along the southeast coast, opposing southwesterly transport paths are implied.

The beach cells along the west coast are supplied from northerly littoral drift and from sediments released from local reef and backshore erosion. Sediment transport is partially localised within these smaller scale systems by fringe reefs at the headlands which act as groynes and influence the energy distribution within the cell and resultant sediment transport. Degradation of the coral population has allowed greater wave energy to encroach on the shoreline. Erosional products from the reefs and from the beaches are taken offshore by cellular circulation and are easily resuspended from offshore by storm swells.

Sand influxes from Cobbler's Reef in the 1970's contributed significantly to accretion along the south coast with westerly sediment transport trapped by artificial structures (e.g. Coast Guard Station; Milton - over 10,000 m³ of sand trapped behind breakwater during 1972).

Sediment transport calculations based on 1983/84 field measurements yielded gross transport rates of the order of 12,700 m³ per year for the west coast with a net southerly transport of approximately 7,400 m³. Dominant sediment transport from the north appears to terminate at the Prospect Bulge after which southerly systems may be dominant. Along the south coast an anomalous dominance of easterly transport (71,000 m³/yr) over westerly (33,000 m³/yr) was noted.

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Prior to settlement, the Barbados south and west coasts were accretional. The fringing reefs and sea grass systems, the Manchineel and mangrove association backshore-vegetation formed a shoreline system that advanced seaward at rates of 1-10 m per century, interrupted only by occasional severe tropical storms. The beaches were very narrow, nearly continuous, with backshore vegetation growing almost to water's edge.

Since settlement, headlands on the west coast have experienced erosion varying from 15 to 110 m with 40-60 m being common over the past three centuries (as measured by the seaward extent of beach rock and by the width of reef flats). Increasing exposure of beach rock (23% linear increase along the west coast and 17% along the south coast from 1962-83) is strong evidence of beach retreat. Greatest recessions appear to have been associated with hurricanes prevalent during the late seventeenth to early nineteenth century. Erosion has been renewed again during the past few decades. These two periods of erosion are evidenced by older and younger beach rock at Freshwater Bay headlands and also by an intervening period of secondary coral succession on the fringe reefs. Shoreline erosion "rates" over the past three centuries on the west coast are estimated at 15 m per century with local headland rates varying from 5 to 35 m per century. Headland erosion appears to occur in "pulses" coincident with periodic intense tropical storms followed by accretional recovery cycles. Greatest recession has been observed at the headlands of Port Denmark, Folkstone, and Freshwater Bay. At many locations the backshore has been "fixed", anchored by revetments and beach structures. As a result, the beaches are rapidly thinning downdrift and are frequently interrupted by eroding foreshores depleted of sands. This discontinuity is a relatively recent phenomenon. Partial removal of beach structures (eg. Golden Palms, Barbados Beach Village) has resulted in marked rejuvenation of the downdrift beaches.

The south coast has been mainly erosional during the post-settlement period. Hurricanes have caused considerable damage resulting in extensive modifications of the shoreline especially at Dover Point where a coastal roadway has been lost and tombolos and embayments appeared and disappeared. Hurricane Janet (1955) made much sediment available for south coast littoral drift during the past two decades. Sea walls and groynes were installed on the south coast throughout this century. The resultant, structurally-trapped artificial beaches do not offer the degree of tropical storm protection provided by natural coral reef-protected and vegetated shorelines. Beach erosion continues. In those areas not protected by seaward structures or nature.

Beach profile measurements (1983-84) indicate values of recession and sweep zone widths far in excess of the previous post-settlement rates of beach recessions.

#### DID THE GREATER ANTILLES ISLAND ARC REVERSE SUBDUCTION POLARITY IN LATE CRETACEOUS TIME?

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Several previous workers have postulated a reversal of subduction polarity or "flipping" of the intraoceanic Greater Antilles island arc in Late Cretaceous time. This reversal in subduction polarity from northeast-dipping to southwest-dipping is attributed to attempted subduction of the buoyant oceanic plateau crust, which now outcrops in Cuba, Hispaniola and Puerto Rico beneath the southern Greater Antilles arc. Subsequently, southwestward subduction of oceanic crust of the Atlantic Ocean led to the Eocene collision between the Bahama Platform and the Greater Antilles arc and sudden Eocene cessation of arc activity.

Data used by previous workers to support a Late Cretaceous reversal in subduction polarity include: 1) the present geographic distribution of presumed paired metamorphic belts; 2) compilation of mainly K-Ar radiometric ages from which temporal clusters of ages are assumed to represent major metamorphic events resulting from collision and subduction reversal; and 3) the age, history and composition of arc volcanism in the Greater Antilles.

In order to address the subduction polarity question, we have studied the age, history and composition of Late Cretaceous arc rocks in the little-deformed Cordillera Oriental of eastern Hispaniola. Our studies and those of Bourdon (1985) have shown that the oldest arc rocks (Guamir Basalts) are pre-Aptian in age and consist mainly of mafic tholeiitic volcanic rocks typical of the Primitive Island Arc (PIA) rock suite. These rocks were uplifted and eroded in pre-Aptian time and are unconformably overlain by 200-300 m of shallow-marine limestone. This limestone is overlain by post-Aptian to Maestrichtian intermediate to felsic pyroclastic rocks with calc-alkaline affinities (Loma La Vega Volcanics).

Compilation of results by previous workers in Puerto Rico, Cuba, and other areas of Hispaniola indicate a similar Late Cretaceous arc history punctuated in Aptian-Albian time by uplift and deposition of shallow-marine limestone. We interpret the regional change in magma types from PIA and CA as reflecting a reversal in subduction polarity from northeast-dipping to southwest-dipping. Compositional variation may result from Aptian-Albian reorganization of the arc mantle and the type of sediment subducted (Atlantic vs. Pacific).

#### AN EVALUATION OF THE DEPTH OF EMPLACEMENT OF GRANITOID PLUTONIC ROCKS IN THE EASTERN GREATER ANTILLES

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Electron-microprobe analyses of magmatic hornblendes from granitoid rocks of the San Lorenzo batholith, the Virgin Islands batholith, the batholith on Vieques island, the Uluado pluton, the Morovis stock, the Rio Blanco stock, and other unnamed intrusions in the eastern Greater Antilles have been carried out for the purpose of estimating the pressures at which these intrusions were emplaced. The intrusions have calc-alkalic chemical affinities and consist mainly of quartz diorite, granodiorite, or quartz monzonite. The hornblendes typically occur in association with quartz, plagioclase, K-feldspar, biotite ( $\pm$ ), Fe-Ti oxides, and sphene ( $\pm$ ).

Utilizing an empirical hornblende geobarometer (Hammarstrom and Zen, 1986, American Mineralogist, v. 71, p. 1297-1313; Hollister and others, 1987, American Mineralogist, v. 72, p. 231-239), the total Al contents of the hornblendes suggest that the intrusions were emplaced at low to medium pressures which correspond to depths of less than about 10 kilometers. Similar pressures of intrusion have been estimated from the metamorphic contact aureoles adjacent to the Virgin Islands and San Lorenzo batholiths. These geobarometric data help characterize the crust in the eastern Greater Antilles and place constraints on minimum crustal thickness in late Cretaceous and early Tertiary time.

#### METALLOGENESIS OF BASE AND PRECIOUS METALS IN NORTHERN HAITI

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Northern Haiti is dominated by the Massif du Nord, a major anticlinal structure which represents the northwestern extension of Cordillera Central, the "backbone" of the Hispaniola segment of the Greater Antilles Cretaceous-Early Tertiary calc-alkaline volcanic arc. The core of the Massif du Nord is made of the widespread Loma de Cabrera batholith, partly floated by Pre-Albian ophiolite suite rocks, black shale units and Mid-Upper Cretaceous andesitic volcano-sedimentary series. Its periphery is marked by a more or less continuous belt of Upper Cretaceous, intermediate to felsic volcano-sedimentary series (La Mine Series) bordered by the overlying Trois Rivières flysch series and Tertiary limestones.

A spectrum of base and precious metal deposits in the Massif du Nord, is spatially and genetically related to two types of high-level magmatic systems, each characterized by distinct lithologies, alteration assemblages, mineral and geochemical associations. The first system is centered on quartz diorite porphyry stocks, high-level periplutonic intrusions of the tonalite batholith, emplaced in Pre-Albian formations and in the deeper zones of the Upper Cretaceous andesitic volcanic pile. Mineral deposits related to this system comprise porphyry copper-bearing stocks, limestone replacement deposits (Cu-Au-Ag skarns) copper-rich veins and auriferous quartz veins. Examples of these deposits are Douvray and Blondin with reserves of 200 million tonnes at 0.6 t Cu and 100 million tonnes at 0.5 t Cu respectively, Mémé former underground mine with potential resource of 3.5 million tonnes at 2 t Cu, 1.8 g/t Au, 10 g/t Ag and Faillle B gold deposit with drill indicated reserves of 520,000 tonnes grading 14.1 g/t Au.

The second major system sits higher in the stratigraphic sequence and represents epithermal polymetallic mineralization associated with dacitic subvolcanic stocks hosted by the La Mine Upper Cretaceous volcano-sedimentary series. Mineralization exhibits volcano-tectonic fracture control and features strong Cu-Zn-Pb-Au-Ag-baryte associations and enrichment in Hg-As-Mo. The maximum gold and silver contents reported from this type of mineralization are 48.5 g/t Au and 640 g/t Ag. Mineralization is characterized by large halo of argillic alteration containing zones of chalcedony silica alteration, sulphide stockworks, massive powder-fine pyritization, barite veins, baryte-sulphide lenses and stratabound replacements. Gold oxide deposits associated with this type of mineralization are Morne Bossa and Grand Bois with 2 million at 2.2 g/t Au and 4.5 million tonnes at 3.0 g/t Au respectively.

PRENEOMORPHIC DIAGENESIS OF CORALS FROM A SUBAERALLY EXPOSED HOLOCENE REEF, ENRIQUILLO VALLEY, DOMINICAN REPUBLIC

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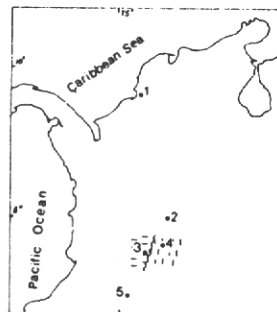
Analyses of major, minor, and trace elements in corals from a subaerially exposed Holocene reef indicate that significant chemical changes occur prior to the neomorphic transformation from aragonite to calcite. Characterization of these chemical changes affords vital information for 1) interpreting diagenetic environments from postneomorphic chemistries of originally aragonitic constituents; 2) interpreting more realistic chemical "baselines" from petrographically pristine constituents; and 3) discerning the mechanisms by which the preneomorphic changes proceed. In order to characterize the changes, new statistical techniques specific to "closed" data (such as geochemical data) have been used. A suite of corals consisting of thirteen different species, still wholly aragonitic, was collected from an emergent reef in the Enriquillo Valley, Dominican Republic. These corals are being compared chemically, species by species, to living corals from several reefs off the western coast of Puerto Rico. The Puerto Rican reefs were selected because they closely resemble the sediment-stressed conditions inferred for the fossil reef in the Dominican Republic. The Dominican Republic reef was selected as the fossil reef of study due to the excellent preservation of the corals and because the geologic history of the reef is well-documented, allowing chemical changes to be related to a priori information about diagenetic environments. Both the preneomorphic chemical changes and possible mechanisms will be discussed.

SANTONIAN FORAMINIFERA FROM COLOMBIA

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During a long time it was suggested the lack of Santonian rocks in Colombia excepting some sparse references on *Lenticeras ballai-Paralenticeras sieveri* a scanty ammonite assemblage found together with *Tenaxites texanus*. A rich planktic foraminifera assemblage was found at five localities spread all over Colombia. This fauna consists mainly of *Rosita fornicata*, *Dicarinella asymetrica*, *D. concavata*, *Whiteinella inornata*, *Maryinotrun-cana sinuosa*, *M. pseudolinneana*, and *Hastigerinoides alexanderi* among others. This finding is the first micropaleontological reference for the Santonian of Colombia, and its biostratigraphic reliability appears to be more practical than those biostratigraphic schemes based on macro-fossils.

In the same way, this assemblage has important palaeobiogeographic implications. It allows, for instance to precise the boundary between two previously proposed microfaunal provinces from Central Colombia (Upper Magdalena and Bogotá). The Girardot area, located along this boundary, is characterized by abundant biminids and rare planktics and suggests shallower conditions than the other samples that are composed entirely of planktic foraminifera. Abundant keeled forms occur, for example, in the Leiva area suggesting offshore (relatively deep water) and anoxic bottom conditions in contrast to previous interpretations that suggested nearshore conditions.



SANTONIAN LOCALITIES

- 1-Chalán
- 2-Leiva
- 3-Girardot
- 4-Pedro Palo Lake
- 5-Paicol

MICROFAUNAL PROVINCES (Peltier, 1955)

- Upper Magdalena
- ... Bogotá

1:100,000 SCALE, GEOLOGIC-TECTONIC COMPILATION MAP, CROSS SECTIONS, AND REGIONAL STRATIGRAPHIC SYNTHESIS OF THE DOMINICAN REPUBLIC

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The island of Hispaniola is a critical area for understanding the geologic history of the northern Caribbean: 1) the island forms the second largest landmass in the Greater Antilles and completely straddles the 200-250 km wide, present-day North America-Caribbean strike-slip plate boundary zone; 2) rapid late Neogene uplift and deep levels of erosion expose an early Cretaceous-middle Eocene intraoceanic island arc and associated near-arc basins and accretionary prisms; and 3) younger late Eocene-Pleistocene strike-slip-related basins are either exposed in areas of late Neogene uplift or are known from recently released oil company seismic data and exploration wells.

We have prepared a geologic-tectonic compilation map of the eastern two-thirds of the island of Hispaniola (Dominican Republic). The map is divided into four sheets and is accompanied by five regional cross sections and stratigraphic correlation charts. A scale of 1:100,000 was selected in order to display individual structural measurements as well as paleontologic sample sites. A topographic and UTM grid base is used to facilitate use of the map in the field. The map displays lithostratigraphic units (formations, members, etc.) and attempts to maintain as much as possible the stratigraphic nomenclature of early workers. Data sources for the compilation includes over 60 published and unpublished maps, reports, theses, and our own unpublished field data.

The compilation map, sections, and stratigraphic correlations help constrain the geologic history of the following features: 1) Cenozoic juxtaposition of early Cretaceous-middle Eocene intraoceanic island arc terranes across WNW-striking, high-angle faults; 2) extent and structural style of early Miocene-Present fold-and-thrust-belt in central and southwestern Hispaniola; and 3) onshore extension of strike-slip faults related to present-day North America-Caribbean plate motion.

INTRAPLATE DEFORMATIONS IN THE WESTERN CARIBBEAN.

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Most of the deformations related to the relative displacement of the Caribbean plate with respect to the surrounding plates are taking place along active plate boundaries, either convergent or transcurrent. In the western Caribbean, however, deformations are also taking place in the Caribbean plate itself. Large folds are being formed in the western Colombian Basin together with rifting and transcurrent faulting along the southwestern and southern edge of the Nicaragua Rise.

Some evidence of these deformations is shown by a few seismic profiles shot a few years ago by french oil companies (ELF-Aquitaine, TOTAL-CFP and IFP). They suggest that a new plate boundary is now developing along the southern edge of the Nicaragua Rise. It seems to branch off the main Northern Caribbean plate boundary east of Jamaica, to follow the trend of the Pedro Bank-Bajo Nuevo fault zone and to include the Providencia Trough. Its connection with the Central American active margins however is poorly understood for the moment.

THE SOUTHEASTERN CARIBBEAN CORNER: A TRIPLE JUNCTION BETWEEN  
CONVERGENT, TRANSCURRENT AND PASSIVE MARGINS.

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Multichannel seismic profiles, field data, and a few wells from  
the oil industry have been used to prepare regional sections  
across the passive and active margins of the Southeastern  
Caribbean Corner. Three margins currently form an active triple  
junction in the vicinity of Trinidad.  
To the south, the Guyana passive margin and the Demerara Rise  
show three main stages of subsidence that occurred in  
Jurassic-early Cretaceous, Late Cretaceous-Paleogene, and Neogene  
times. To the north, the southern edge of the Barbados Ridge  
currently involves the distal part of the Orinoco deep sea fan,  
with wide eastward verging anticlines, intervening piggyback  
basins and a few E-W dextral faults. To the west, the  
southeastern Caribbean margin results from transcurrent dextral  
shearing and oblique collision between the Lesser Antilles Island  
arc and the northern South American margin.  
A particular feature of the onshore and offshore thrust belts  
around Trinidad is the presence of mud volcanoes. Overpressuring  
at depth could result from the difficulty the water has in  
escaping from the clays when the main compressive stresses are  
horizontal. Such a stress pattern will prevent the opening of  
vertical tensional gashes along which the primary migration of  
water is believed to occur in sediments with initially low  
permeability.

GEOLOGICAL MAP OF THE CARIBBEAN

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This new geological map of the Caribbean (1:2,500,000th scale) is expected to be  
published in 1989.

The map has been prepared at the Institut Français du Pétrole, with the  
collaboration of BEICIP, IFREMER, Elf Aquitaine and Total-Compagnie Française des  
Pétroles. Special attention has been given to the onshore and offshore  
sedimentary basins.

A small booklet will accompany the map to explain the structure and evolution of  
the Caribbean margins.

STRATIGRAPHY AND TECTONIC ANALYSIS OF THE SERRANIA DE  
TRUJILLO IN THE BOUNDARY OF MARACAIBO BASIN, FALCON  
RANGE AND CARIBBEAN CHAIN, N W VENEZUELA.

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The Serrania de Trujillo-Ziruma lies to the East of the Maracaibo Basin, at the  
junction of three structural provinces: the allochthonous Caribbean Chain (E),  
the autochthonous of Maracaibo Basin (W), and the Oligo-Miocene Falcon Basin  
(NE). The Burro Negro fault is an important feature in the studied area since it  
separates 2 structural trends; the first corresponds to the southern block with a  
NW-SE trend. A NE-SW to N-S structural trend is observed near the Valera  
major Fault zone. Apart from the Jurassic-Cretaceous tectonic wedge situated  
along the left lateral Valera strike-slip fault zone, the sedimentary deposits that  
form the Serrania are Tertiary in age. Above the Upper Paleocene shaly  
limestone, three major sedimentary cycles can be observed. The turbiditic  
sequences of the Lower Eocene (Fm. Trujillo) are characterized by two  
conglomeratic levels and olistoliths of Cretaceous limestones, and represent the  
distal flysch of the Lara Complex (allochthonous Caribbean Chain). During the  
Middle Eocene, Maracaibo Basin fluvio-deltaic complex prograded towards the  
NE (Fm. Misos). The Upper Middle Eocene transgression (Agua Negra Group)  
occurs on deformed structures, (N 160 E Middle Eocene compressive phase).  
The Upper Eocene-Oligocene records two tectonic events: a major compressive  
phase N 110 E and a minor N 20 E.  
In Lower Miocene (Burdigalian), the Falcon Basin transgression begins with the  
sandstone feeding. The major compressive phase (N 130-140 E) which occurs at  
the end of the Miocene, has reorganized the Eocene folds.  
The Plio-Quaternary andean uplifting affects the Serrania, showing two tectonic  
events E-W and N 170 E. The Serrania de Trujillo-Ziruma represents an  
allochthonous range, with a complex tectonic history, according to a NW-SE to  
SW-NE compressive stress pattern.

Ref. : MATHIEU X., (1989).- Analyse stratigraphique et tectonique de la  
Serrania de Trujillo aux confins du Bassin de Maracaibo, de la chaîne du Falcon,  
et de la Chaîne Caraïbe, au N W du Venezuela. Ph.D. thesis University of Brest,  
France, June 1989.

BIOSTRATIGRAPHY, AND PALEOECOLOGIC SIGNIFICANCE OF  
CALCAREOUS-SILICEOUS FACIES OF THE NEOGENE MONTPELIER  
FORMATION, NORTHEASTERN JAMAICA.

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The Spring Garden Member of the Montpellier Formation exposed  
on the northeastern coast of Jamaica at Buff Bay includes an  
interval of calcareous-siliceous facies composed of abundant  
sponges spicules with varying amount of radiolaria. Triaxon  
and Tetraxon spicules of the Hyalospongia group dominate the  
biogenic silica components (60-93%), whereas radiolarian  
assemblages are impoverished to well diversified. Index  
radiolarian taxa such as *Calocyclus costata*, *Dorsodasyria*  
*dentata* and *Liriospyria globosa* at the base of the exposed  
outcrop indicates a minimum age of late Early Miocene,  
*Calocyclus costata* radiolarian zone, for the occurrence of  
the calcareous-siliceous facies. This age is in agreement  
with the foraminiferal assemblage at this level, which  
comprises *Globigerinella insueta*, *Globorotalia*  
*peripheroronda* and *Globigerinoides sicanus* (without  
*Prætorbulina glomerata*) indicative of the *Globigerinella*  
*insueta* foraminiferal zone. Therefore the base of the  
sequence lies within zone N7 or N8 of Banner and Blow.

The upper limit of the calcareous-siliceous facies lies  
within the upper part of the *Brachyspyria alata* radiolarian  
zone of early Middle Miocene age, as indicated by the  
presence of the nominate radiolarian taxon of the zone, and  
the absence of *Cannartus violina*, *Calocyclus costata* and  
*Cyclampterium leptum*. This zone corresponds to the upper  
part of the *Globorotalia peripheroronda* foraminiferal zone as  
shown by the presence of *Globigerinoides sicanus*, *Orbulina*  
*unversa*, *Globorotalia praememardii*, and the absence of  
*Globigerinella insueta* (Zone 8-9 of Banner and Blow). This  
calcareous-siliceous facies is interpreted to have developed  
over a neritopelagic bank influenced by strong bottom  
current, a situation that finds its modern analog in the  
present area of the Hatton Bank and Rockall Plateau where  
subsurface flow of the North Atlantic Deep Water (NADW)  
controls high productivity of Hyalospongia. Radiolaria  
productivity was irregular and controlled by dynamic  
divergence which occurred in relation to the  
paleogeography of the bank as well as forcing mechanisms  
associated with minor climatic fluctuations of that time.



# EARLY METEORIC DIAGENESIS OF CARBONATE SANDS AT OCEAN BIGHT, GREAT EXUMA ISLAND, BAHAMAS

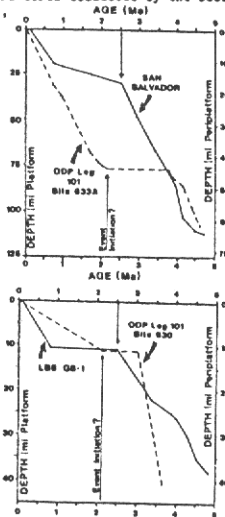
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Ocean Bight contains a Holocene strand-plain, deposited in a pocket between two Pleistocene headlands on the island of Great Exuma, Bahamas. Like many similar deposits throughout the Bahamas, the plain consists of multiple ridge and trough couplets which trend parallel to the modern shoreline and represent repeated episodes of beach accretion. Very fine to coarse grained bioclastic carbonate sands compose the deposit. Grain types include coral, green algae (*Halimeda* sp.), mollusc, coralline algae, and foraminifera fragments. The strand-plain contains a lens of fresh ground water with areal dimensions corresponding to those of the Holocene deposit (~1.5 km<sup>2</sup>) and a maximum thickness in excess of 6 meters. As a result of the presence of fresh ground water, diagenetic processes are altering the existing metastable mineral assemblage to low-magnesian calcite. Cementation associated with this alteration is found to occur in the vadose and upper phreatic zones, and is often exposed at ridge crests where deflationary processes have unearthed vadose cementation. In the vadose zone, cementation appears at approximately 10cm below the ground surface. Here, cementation is irregular and somewhat mottled in appearance. Areas of cement are routinely interrupted by areas of completely uncemented, organic rich sands with abundant plant roots. Mottled vadose cement grades downward into more pervasive, fabric selective cement. This transformation occurs within 20cm of the water table (~1.5m subsurface). Following this transformation, pervasive cementation usually continues into the upper phreatic zone. An unexpected transformation occurs, however, at depths ranging from 2-3m below the water table. Pervasive void filling cement gives way to a virtual absence of cement despite the presence of fresh ground waters. Of the seven wells drilled into the deposit, all encountered this uncemented zone and further showed it to continue to the Holocene/Pleistocene contact. One explanation for this observation is that the oxidation of organic matter by sulfate derived from aerosols causes a reduction in pH and a consequent undersaturation with respect to all carbonate species. This hypothesis is supported by pH measurements and a strong smell of H<sub>2</sub>S. Further analyses of alkalinity, calcium, sulfate, and chloride concentrations should confirm this interpretation.

# SEA LEVEL INDUCED EROSIONAL EVENTS IN PLATFORM/PERIPLATFORM SEDIMENTS, AND THE FORMATION OF LONSTAND DEPOSITS

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Net accumulation curves for Bahamian platform and periplatform carbonates are used to elucidate, with good time control, a regional scale erosional event believed to be triggered by sea level regression. Magnetostratigraphic dating of cores from Little Bahama Bank and San Salvador in conjunction with nearby biostratigraphically and magnetostratigraphically dated periplatform cores collected by the Ocean Drilling Program Leg 101 (sites 633, 630), allow comparison of periods of accumulation and erosion (see figures). These two periplatform cores (and 4 additional ODP cores) show an erosional gap from about 2.2 to over 3.0 Ma, whereas the platform record shows the onset of subaerial exposure at about 2.4 Ma, continuing to about 0.8 Ma. Overlap of these two profiles suggests that a regional scale erosional event, likely slope failure as an avulsing gravity flow, occurred just after initial exposure of the platform between 2.4-2.2 Ma. Net accumulation curves suggest that this event occurred after a prolonged highstand capable of producing and storing large quantities of uncemented sediment. Following the concept of Crevello & Schlager (1980), this large sediment reservoir may have loaded the platform margin and upper slope as sea level and wave base regressed. These data suggest that initial lowering of sea level triggered this regional erosion event on the platform flanks thus moving periplatform sediment basinward, although other triggering mechanisms are possible (i.e. tectonic). This sequence of events may partially explain the lonstand deposits in seismic profiles of pure carbonate environments.



# FORAMINIFERA, PALEOENVIRONMENTS, AND BASIN EVOLUTION, S.W. DOMINICAN REPUBLIC

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The Azua Basin is an elongate, thrust-fault bounded synclinal sedimentary trough filled with over 2,500 m of Miocene and Pliocene marine sedimentary rocks. The lower part of the sequence reflects a change from a deep carbonate basin setting, represented by the Sombrero Formation, to a prograding turbidite regime, represented by the Trincheras Formation. The Trincheras ranges from lower Miocene (*Oligobaculites insuetus* chronozone) to middle Miocene (*Oligobaculites lobatus* c.z.), and its Gajo Largo Member spans the middle-upper Miocene boundary (*Oligobaculites mayeri* c.z. to lower *Oligobaculites apiculatus* c.z.). The Trincheras spans an interval from near the middle-upper Miocene boundary (*Oligobaculites mayeri* c.z. or *Oligobaculites apiculatus* c.z.) to the lower Pliocene (*Oligobaculites mayeri* c.z.). The upper part of the sequence reflects a transition from shallow-marine to lagoonal pelagial environments. The Quila Carrera Formation lies in the lower Pliocene (*Oligobaculites mayeri* c.z.). The lower part of the Arroyo Blanco Formation ranges from uppermost Miocene (upper *Oligobaculites humerosus* c.z.) to lower or middle Pliocene (*Oligobaculites mayeri* c.z. or *Oligobaculites humerosus* c.z.).

Principal components analysis of rich benthic foraminiferal faunas aided in the recognition of significant species associations based on the loading of species on six factors. Factor 1 represents an uppermost bathyal assemblage, with strong positive factor loadings on *Bolivina minima* (0.68), *Cassidulinella nortoni* var. *australis* (0.73), and *Ammonia beudanticus* (0.71). Lower bathyal species such as *Pleurostomella sherrini* (-0.64), *Bolivina paula* (-0.62), and *Cibicides wuellerstorfi* (-0.49) show strong negative loadings. Factor 2 represents middle to upper bathyal assemblages; *Oligobaculites humerosus* (0.68), *Hyperbundance elegans* (0.57), and *Uvulserina perrini* (0.51) all have strong positive loadings. Factors 3, 4, and 5 all have positive loadings of neritic species. Factor 3 represents a middle to outer neritic assemblage that includes *Ammonia lineata* (0.83), *Cassidulinella subulobosa* (0.59), *Cassidulinella carinata* (0.64), and *Cibicides pachydermus* forma *subulobosa* (0.51). Factor 4 has heavy loadings on inner neritic species including *Hyperbundance elegans* (0.74), *Uvulserina perrini* (0.73), and *Rosellina carinata* (0.66). Species having strong associations with Factor 5 include *Cibicides lobatulus* (0.69), and *Bolivina loebbeckii* (0.59). Factor 6 represents a current-winnowed assemblage. Plots of the factor scores in the stratigraphic sections demonstrate shoaling upward from lower bathyal to inner neritic depths, this trend is paralleled by decreasing diversity and by lithofacies progressions. Cluster analysis reveals seven major sample groupings that correspond almost directly to the faunal zones identified in the Azua Basin by Bermudez (1949).

Placed within the biostratigraphic framework for the basin, the benthic foraminiferal trends indicate migration of paleoenvironments toward the Caribbean during the Miocene and Pliocene, paralleled by a similar time-transgression of lithofacies. This suggests that basin evolution has been controlled by tectonic activity along the northern boundary of the Caribbean Plate, and that it proceeded in two stages: 1) a tectonically quiet open ocean stage before the late Miocene, 2) a subsequent tectonically-active, laterally-constrained clastic basin stage. The large volumes of clastics laid down during stage 2 indicate uplift and erosion of the Cordillera Central. The east-parallel paleocurrents in the Azua Basin suggest contemporaneous uplift of the Sierra de Neiba as the laterally-constraining structure. These events are interpreted to represent rapid filling of a "ramp valley" basin by sediments derived from the uplift of the nearby Cordillera Central, coincident with activation of the Hispaniola restraining bend in the late Miocene.

# FROM A VOLCANIC CRISIS TO A VOLCANIC HAZARD ASSESSMENT PROGRAM: THE GUATEMALAN CASE

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In June, 1986 we undertook an emergency hazard assessment of Tacaná Volcano, Guatemala at the request of the United Nations Disaster Relief Organization. Very little was known about Tacaná, but the start of fumarolic and seismic activity gave rise to fears that a major eruption may take place. Hazard maps and assessments were made and will appear in a forthcoming issue of GEOFISICA INTERNACIONAL. Although only minor phreatic eruptions took place, this activity heightened fears concerning the much more active Pacaya, Fuego, and Santiaguito volcanoes. It was clearly seen that hazard assessments were much better carried out on a preventive, rather than an emergency, basis.

Six months later another volcanic crisis occurred in Guatemala as Pacaya had a series of explosive eruptions. The USGS, in cooperation with Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH), did a preliminary hazard assessment of Pacaya in February, 1987. Shortly afterwards, the Agency for International Development, USGS, and INSIVUMEH formalized an agreement to develop a local capability for volcanic monitoring and hazard assessment in Guatemala. Because of our familiarity with Guatemalan volcanoes, our group at Michigan Tech was asked to do the hazard assessments and train the Guatemalans in this work. Assessments for the frequently active Fuego and Santiaguito volcanoes have been carried out, in addition to reconnaissance work on the identification of volcanic collapse deposits in the Highlands of Guatemala. A geologist from INSIVUMEH spent 7 weeks at Michigan Tech and at the Cascades and Hawaiian Volcano Observatories getting intense training on volcanological work.

The project is on its second year, but some important issues remain unsolved. Logistic problems are considerable (e.g., obtaining visas for Guatemalan scientists to visit the States for training). Coordination of 3 different bureaucracies (INSIVUMEH, AID, USGS) is also a source of delays (e.g., field seasons can last 8-10 weeks, yet rules at INSIVUMEH allow only 30 field-days for any given project). Local data gathering can be an exercise in frustration (e.g., data from other Guatemalan agencies is almost impossible to obtain). Inter-institutional and personal rivalries in Guatemala also result in slowing down the hazard work. These problems are being addressed and, although not fully solved yet, we have reasons to believe the hazard assessment program in Guatemala will be a success.

# VOLCANIC HAZARD ASSESSMENT OF TACANA, FUEGO, AND SANTIAGUITO VOLCANOES, GUATEMALA

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Volcanic hazards are a serious concern in Guatemala, a country with several dozen active volcanoes and a population which is concentrated in the same areas. Fuego, Santiaguito and Pacaya are frequently active; Tacaná has given signs of renewing eruptive activity; Tajumulco, Cerro Quemado, Atitlán, and Acatenango have been active in historic times. A program of systematic hazard mapping is currently in effect. We have made hazard maps for Tacaná, Fuego, and Santiaguito. The USGS carried out the assessment for Pacaya.

Tacaná is an andesitic volcano with no historic record of magmatic eruptive activity. Last magmatic activity occurred several centuries ago judging by the degree of revegetation of lava flows. The historic record suggests a pattern of periods of seismic/fumarolic activity spaced 1/4 to 1/2 century apart. At least 2 dacitic prehistoric plinian deposits were discovered. Serious hazards are likely when a magmatic eruption occurs causing ashfall, lava flows, lahars and floods. Evacuation of this remote area will be difficult. Settlement patterns at Tacaná do not indicate any perception of possible volcanic hazards.

Fuego is a frequently active stratovolcano characterized by mafic vertical eruptions from the summit crater accompanied by pyroclastic flows. Last major eruption occurred in 1974; fumarolic activity has characterized the past decade. A radial pattern of pyroclastic flow and lahar hazard zones controlled by the summit crater rim geometry is observed. Lahar and flooding hazards are considerable, and extend at least 25 km to the south. The frequent activity has controlled settlement patterns; the most hazardous areas are uninhabited.

Santiaguito is a continuously active dacitic dome located in the 1902 eruption crater of Santa María volcano. Activity is characterized by 1-5 small ash eruptions/hr from Caliente vent, and avalanching from a 5 km long lava flow. Hazard zonation is controlled by the asymmetrical southward slope of basement topography, parallel drainages, and very high rainfall. The 1902 crater symmetry also directs hazards southward. The 1929 dome collapse and associated pyroclastic flows killed as many as 5000 people. In recent years Santiaguito's continued extrusion has triggered extensive lahars and flooding along rivers south of the dome, affecting several towns.

Ashfall hazards are controlled by the seasonal dependence of wind directions, with easterly winds prevailing from June to November, and westerly winds from December to May. Ashfall from Fuego could affect Antigua and Guatemala City, even in the case of minor activity.

All 3 of these volcanoes have a possibility of edifice collapse. Fuego has collapsed twice in the past, producing large debris avalanches. Tacaná is characterized by prominent faulting which could suggest collapse and Santa María's 1902 crater forms a dramatically oversteepened scarp facing SW.

# EVOLUCION DE LA ESTRUCTURA DEL MACIZO DE ESCAMBRAY

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Las secuencias jurásico-cretácicas del macizo del Escambray conformaron primeramente una sucesión de nappes y escamas apiladas una sobre el otro, destacándose 6 nappes principales (el más superior se emplazó posteriormente) y diferentes tipos de secuencias. Luego se sometieron a un proceso metamórfico con la ocurrencia de 5 fases (6 etapas) de plegamiento, cada una de las cuales se asocia con un sistema de esquistosidad o olijaje con sus tendencias definidas. El estilo de los plegues varía en dependencia de la fase y del área; sus órdenes alcanzan hasta muchos centenares de metros. La fase 1 dio lugar a una esquistosidad con una tendencia NE a N-NE y plegues isoclinales. La fase 2 conformó 2 grandes antiformas con una estrecha sin forma intermedia que se acuna hacia el Norte. La occidental es cupular elongada hacia el NO; mientras que la oriental está elongada más hacia el N-NO, desapareciendo al norte para formar parte del plan estructural de la primera. El sistema de esquistosidad relacional contornea a las antiformas y se asocia con plegues isoclinales. En ambas antiformas se destaca otra esquistosidad más tardía en su parte axial, dispuesta concordantemente con sus ejes de elongación. La fase 3 - se dispone siguiendo una tendencia arqueada independiente en cada megaestructura. Esta fue intensa en la antiforma occidental y su efecto incrementó el desarrollo de la sinforma hacia el Norte. Las fases 4 y 5 imprimieron la elongación final hacia el O-NO de las antiformas. Finalmente las rocas fueron intensamente fracturadas. Las secuencias primarias del macizo se depositaron en un margen continental. Su apilamiento en nappes, metamorfismo y plegamientos asociados, son consecuencia de una colisión ocurrida en el Cretácico Superior entre este margen y el arco volcánico cretácico; en la parte basal de este último ya se dispone al complejo anfibolítico Mabujina (CM). Debido a ello estas secuencias intracorierrón debajo del CM, metamorfozándose y multiplegándose en condiciones de un bajo gradiente temperatura/presión. El CM fue deformado conjuntamente con las mismas y su parte basal parcialmente reelaborada por el metamorfismo. Al desaparecer el estado compresivo vinculado con la colisión, las 2 megaestructuras positivas emergieron en forma diapírica, atravesando las rocas más densas del CM durante la búsqueda del equilibrio gravitacional.

# GREAT BAHAMA BANK WHITINGS: CHEMICAL EVIDENCE FOR DIRECT PRECIPITATION

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Whitings are milky clouds of water, rich in suspended carbonate mud, that drift amongst clear waters in carbonate environments. The formation of whitings on the Great Bahama Bank has long been a subject of controversy. Various workers have suggested that whitings can be produced either from direct precipitation or as a result of resuspension of bottom sediment by fish.

In order to further constrain the origin of whitings we have measured changes in alkalinity and pH between the whitings and adjacent 'clear' waters. Sampling was carried out during July and August, 1988, in an area west of Andros (25°00'N lat. 78°45'W lon.) on Great Bahama Bank. Seawater filtrates were later analyzed for chlorophyll concentrations.

Similar to previous workers (Morse, 1984, JGR, 89:3604), we observed a decrease in alkalinity across the bank, consistent with a gradual removal of CaCO<sub>3</sub>, either as an inorganic or organic precipitate. Individual whitings revealed conflicting results. In some whitings sharp decreases in alkalinity were observed relative to adjacent clear bank waters. In other instances, either slight increases in alkalinity, or no changes were observed. In a previous study, (Morse, 1984) no significant differences in alkalinity were detected between waters inside and outside whitings. One possible explanation for these results is that changes in saturation within the whitings are produced through photosynthetic activity. The process of photosynthesis removes CO<sub>2</sub>, thereby increasing pH and supersaturation with respect to calcium carbonate. The resultant change in saturation causes CaCO<sub>3</sub> to precipitate and alkalinity to decrease. The varying results in our and previous studies could be explained by differing amounts of photosynthesis and respiration in the whitings at the time of sampling. In support of this idea we note that chlorophyll concentrations were three to four times higher in the whitings than in the surrounding water. Such evidence may give credence to the notion that Bahama Bank whitings precipitate or are formed directly from seawater.

# ESQUEMA LITOLÓGICO-PALEOGEOGRÁFICO DE CUBA EN EL INTERVALO PALEOCENO-EOCENO MEDIO

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Este esquema se ha confeccionado con el objetivo de que sirva de base para la localización de áreas prospectivas para fosforitas, rocas fosfóricas y prospección de ellas en sedimentos de edad Paleoceno-Eoceno Medio, considerando que en sedimentos de la misma edad se encuentran grandes yacimientos de esta materia prima en la Península de Florida.

Para la preparación de este esquema se estudiaron las siguientes cuencas: Los Palacios, Bahía Honda, Vega-Mercaderes, Santo Domingo, Cienfuegos, Trinidad, Cabaiguán, Cuenca Central, Cauto-Nipe y Guantánamo, analizando las formaciones geológicas que en ellas se encuentran para la discriminación de aquellas con mayores perspectivas.

Los autores consideran que además de la zona occidental de nuestro territorio, donde es conocido el yacimiento La Pimienta, debe centrarse la atención, en los horizontes carbonatados - clásticos de la Cuenca Central que yacen transgresivamente sobre los granitoides que constituyen el núcleo mineral accesorio y en formaciones de la zona oriental en cuyos espesores toman parte algunas calizas que contienen abundante material orgánico-detritico, además hay otras unidades litostrostratigráficas que presentan interés desde el punto de vista facial y genético para la futura prospección de rocas fosfáticas.

También presentan cierto interés, algunas formaciones de la Cuenca Santo Domingo compuestas por secuencias clásticas y carbonatadas que sufrieron la acción de la actividad hidrotermal.

Asimismo en las regiones de Madruga, Cabañal y Bahía Honda se conocen secuencias terrígeno-clásticas y carbonatadas donde existen manifestaciones hidrotermales que podrían acarrear soluciones fosfáticas.

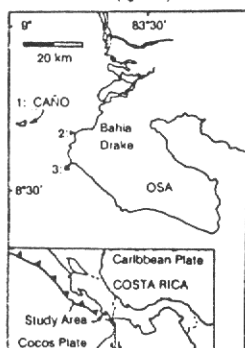
Horizontes con condiciones favorables para la solución de esta materia prima han sido sugeridos para las demás cuencas con menor perspectiva que las antes mencionadas.

# Eocene shallow water carbonate facies with larger foraminifera in the Caño accretionary complex, Caño Island and Osa Peninsula (Costa Rica, Central America)

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The Caño Island is located at the shelf edge 15 km NW off the Osa Peninsula (Bahía Drake, see figure) and 20 km NE of the axis of the Middle American trench, which forms the boundary between the subducting Cocos plate and the Caribbean plate. The island is entirely built by a pervasively tectonized mélange of sedimentary rocks. Massive dark green mylonitic mafic volcanic greywacke (90%) dominate over pelagic limestone, chert and redeposited shallow water carbonates (together 10%) which occur as single dm- to m-sized blocks or in shear-bounded, highly deformed 1-20 m thick boudinaged layers with transitional contacts to the greywacke matrix. These layers are interpreted as tectonized debris flows or turbidites.

On the NE and SE coasts of Caño Island (figure: 1) redeposited shallow water material occurs in isolated blocks of calcarenites and calcirudites showing clasts of lime packstones, grainstones and bindstones and grains of basalt, chert, K-feldspar, and chert. The limestone clasts contain the following bioclasts: articulate coralline algae (dominant), larger foraminifera, smaller planktonic and benthic foraminifera, crinoids, siliceous sponge spicules, bryozoans and green algae. The clasts show stylolitized contacts and several phases of fracturing and vein infill by opal-quartz and then calcite. Similar outcrops of shallow water material occur along the NW coast of Osa: Playa Colorado (Bahía Drake, Azema et al. 1983), Punta San José (figure: 2), San Pedrito and Punta Urona (figure: 3).



Although the larger foraminifera found at the studied localities are recrystallized, partly silicified and fractured, several different assemblages could be identified (locality number in parenthesis): *Amphistegina grimsdalei* (1), *Amphistegina lopertrigoi* (1), *Amphistegina parvula* (1), *Amphistegina pregrimsdalei* (3), *Amphistegina* sp. (2), *Asterocyclina* sp. (1), *Boreoloides* (2), *Discocyclina* sp. (1, 2, 3), *Eoconuloides* sp. (1, 3), *Eotabiania cushmani* (1), *Eotabiania* sp. (1), *Fabiania cubensis* (1, 3), *Helicostegina dimorpha* (3), *Helicostegina polypralis* (3), *Helicostegina* sp. (2, 3), *Lepidocyclina* sp. (1), *Linderina* sp. (1, 3), *Nummulites floridensis* (1), *Paratella* sp. (1), *Sphaerogypsina globulus* (1). These assemblages indicate a middle Eocene age (2, 3) and late Eocene age (1) with reworking of middle Eocene forms.

The intensely deformed sedimentary mélanges found on Caño and Osa are interpreted as accreted volcanoclastic slope deposits with associated time turbidites/debris flows derived from ephemeral platforms. These sediments may represent a trench fill which became accreted to the Middle American arc in post-Eocene times.

# Tectonostratigraphy of the San Francisco Ridge area in the northeastern Cibao Valley, Dominican Republic.

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Neogene strata exposed along the San Francisco Ridge (SFR as named by the author), which is near the city of San Francisco de Macoris in northeastern Hispaniola record the tectonostratigraphic evolution of a former marine basin, the present day Cibao Valley, which is adjacent to a now uplifted subduction complex, the Cordillera Septentrional. Deep-water calciclastic strata of Miocene age are unconformably overlain by shallow-marine carbonate strata of early Pliocene age. These strata are in turn unconformably overlain by mainly fluvial channel deposits of later Pliocene age or younger.

In the SFR, Miocene strata are folded and faulted which indicates that uplift and deformation occurred since latest Miocene time. The intense deformational event ceased by early Pliocene time as indicated by the much less deformed Pliocene strata. A Pliocene or later deformational event resulted in the present relief of the SFR as evidenced by the broad warping of the Pliocene strata over the SFR.

# DOS TIPOS DE COMPLEJOS ULTRABÁSICOS EN LA ESTRUCTURA DE CUBA ORIENTAL

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Las ultrabásitas del primer tipo pertenecen a ofiolíticas del Mesozoico Tardío, presentes en las unidades estructurales inferiores de la zona Auras y del alóctono Moa-Baracoa. Estos alóctonos ofiolíticos y tradicionalmente se han considerado como fragmentos de la litosfera de la cuenca oceánica del norte de Cuba y no serán discutidos aquí. Las ultrabásitas del segundo tipo están representadas por cuerpos embudiformes que se hunden verticalmente a gran profundidad, bordeados por campos de cuerpos tabulares, turbiditas y brechas ultrabásicas. Un ejemplo de este tipo de cuerpos ultrabásicos lo constituyen los macizos de Sierra de Nipe y Sierra del Cristal. Este último transiciona hacia el este a una alternancia de ultrabásitas y brechas ultrabásicas, las cuales, a su vez, pasan más al este al flysch de la Formación Micara, el cual contiene horizontes de brechas, turbiditas ultrabásicas y olistostromas. En contenido de minerales de alta temperatura de las dunitas y harzburgitas del río Arroyón, de fragmentos de hiperbasaltos concentricos zonados con una orla de fragmentos de columnares radiales (indicador de enfriamiento rápido), indican que el emplazamiento de las rocas ultrabásicas en los depósitos de flysch pudo haber ocurrido en forma de un diapiro del manto en estado caliente, el cual sufrió desintegración y estratificación del material incandescente de su núcleo en el proceso de salida hacia los horizontes superiores de la corteza terrestre, como resultado de un "choque" térmico y descompresión. Entonces, en forma de una masa fragmentada extrusiva fue exprimido hacia la superficie, a través de brechas y turbiditas ultrabásicas hacia la cuenca de deposición de la Formación Micara. Esta asociación constituye fragmentos de basamento ultrabásico y de la cobertura flysch-olistostromática de la depresión suboceaánica Cauto-Nipe. La depresión Cauto-Nipe surgió en el Campaniano Superior-Maestríctiano Inferior en una zona de rift que provocó la apertura de los complejos del arco insular cubano y de la corteza oceánica de la cuenca del Norte de Cuba. Precisamente con la apertura de esta estructura transversal se vincula el sentido del movimiento del alóctono Moa-Baracoa, inverso con relación al sector central de Cuba. Esta zona de apertura representaba, probablemente, la continuación de las fallas de transformación del Atlántico y constituida, al mismo tiempo, el eje de apertura de la Cuenca de Yucatán, cuyos marcos temporales de desarrollo coinciden con los de la depresión Cauto-Nipe.

# FORENSIC GEOLOGY: NEW APPLICATIONS OF STANDARD PROCEDURES

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Two recent court cases involved the theft of cargo and the substitution of sand for the original cargo. In the first case a "piggy-back" cargo container arrived in Miami having traveled by truck from Paraguay to Santos, Brazil and then by freighter to several ports in Brazil and on to Miami. When the container arrived in Miami it was sealed and its papers were in order, the weight having been checked several times enroute. When the container was opened, however, the original cargo was seen to have been replaced by sand. One of several insurance companies was liable but the problem was which one? The question was, where had the switch taken place?

In the second case, a cargo container arrived in Argentina having been shipped from Miami, and again the original cargo had been replaced by sand either in the Miami area or in and around Buenos Aires, Argentina. It was important to the court in Argentina to know whether the switch was done in Miami or Buenos Aires. In both cases, since the tonnage of sand involved was fairly large, the assumption was made that the sand was taken from a local source near where the switch had taken place. Therefore the problem was to fingerprint these sands and tie them to some local source. The easiest way to do this, it seemed to me, was to do a provenance study by standard grain size analysis and thin section studies and then to try to match the sands to samples in the field. Some likely source areas were selected and others eliminated by studying the route of cargo travel on geologic maps and reference sand samples in the extensive collection at the Department of Geological Sciences, University of Miami and samples from the collections of Dr. Paul Potter at the University of Cincinnati. Both cases were settled on the basis of these studies.

# AUTOCTONIA O ALOCTONIA DE LA FAJA DE VILLA DE CURA. UN DEBATE HISTÓRICO.

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El Grupo Villa de Cura del norte de Venezuela, fue definido como unidad litostratigráfica por Shagam (1960), Menéndez (1965) y Jarvis (1966) postularon su origen aloctono, lo cual de hecho implicó proponer su formación en algún lugar al norte de la Cordillera de la Costa ("Venezuelan northern coast range") y su posterior deslizamiento gravitacional hacia el sur durante el Cretácico tardío - Paleoceno. Para los autores citados, esta hipótesis fue necesaria a fin de explicar los aspectos siguientes: a) El ambiente de deposición de la Formación Paracotos, b) la aparente similitud litológica entre las formaciones Paracotos y Mucaria, c) el supuesto plegamiento pre-Paleoceno evidente tan solo a lo largo del cinturón de Paracotos y en el lado sur del bloque de Villa de Cura y d) supuesta evidencia indicativa de que la fuente de sedimentos del Grupo Caracas fue esencialmente granítica y se encontraba al sur. Autores más recientes han mantenido el mismo criterio sin proporcionar datos adicionales que permitiesen sustentar, más allá de la especulación geológica, la hipótesis mencionada. En contraposición Taluider et al. (1982), Navarro (1983), Ostos y Navarro (1986), Navarro et al. (1987a, 1987b, 1988) y Navarro (1988) argumentan en favor de la autoctonía del Grupo Villa de Cura, apoyándose en datos geoquímicos, petrológicos, estructurales y geocronológicos, los cuales permiten explicar el origen del bloque partiendo de un marco tectónico completamente diferente, el cual se basa en la generación de una pequeña cuenca oceánica por expansión en el borde norte del cratón de Guayana (de acuerdo a evidencia presentada por Feo Codecido et al., 1984), en la cual se formaron las rocas correspondientes al grupo citado y unidades asociadas.

## POROSITY AND PERMEABILITY DEVELOPMENT IN THE OLIGOCENE-MIOCENE BLUFF FORMATION, GRAND CAYMAN.

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Present day porosity and permeability in the Bluff Formation of Grand Cayman is a result of numerous constructive and destructive processes. Porosity was created by (1) preferential dissolution of aragonitic fossils, (2) solution widening of joints and fissures, (3) development of solution caverns and passages, (4) selective dissolution of the cores of dolomite rhombs, (5) microborings, and (6) tree root borings. The high permeability is related to the extensive network of joints which transect the island and the well developed karst system. Porosity and permeability destruction occurred through the (1) deposition of caymanite, grainstones, terra rossa, and (2) precipitation of speleothemic calcite and carbonate cements. The complex geological development of the porosity and permeability can, however, be deciphered by considering all aspects of the geological history of the island.

The creation and destruction of the porosity in the Bluff Formation was controlled by the interplay of climatic conditions and the successive cycles of regressions and transgressions that have affected Grand Cayman over the last 30 million years. During some regressions porosity was created since the carbonates were exposed to the influx of fresh water. At other times, however, conditions were suitable for the formation of speleothemic calcite, calcite and dolomite cements and/or terra rossa and this led to porosity reduction. The onset of transgressive conditions led to porosity destruction since marine sediments were commonly brought onshore and flushed into the cavities via the well developed joint and cave systems.

The combination of constructive and destructive processes has produced a heterogeneous aquifer of which the hydraulic information is difficult to interpret. The integration of hydrogeological data, hydrochemical information and the geological evolution of the island has led to an improved understanding of the manner in which the groundwater behaves because water-rock interactions affects the hydrogeological properties of the aquifer and hence, the ground water flow. Such information is invaluable in the development and management of this valuable resource.

# TOXIC SUBSTANCES IN THE COASTAL ENVIRONMENT OF THE U S VIRGIN ISLANDS. 1986

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Bottom sediment samples collected in March 1986 from four major impact areas off the U S Virgin Islands during the pilot phase of a two-tiered investigation were analyzed for all 129 USEPA priority toxic substances. Since all organics proved to be below detection limits, the emphasis of the second phase, July/August 1986, was on the 13 USEPA priority toxic trace elements in sediments and seawater sampled from 24 stations around the three major islands. (9 each off St Thomas and St Croix, 6 off St John).

Elevated concentration levels were detected for Ni, Pb, Hg, Zn and Cu, in decreasing order. The rank by overall degree of marine pollution was St Croix > St Thomas > St John. HCVIC Harbor, St Croix was the most impacted site, showing a heavy degree of pollution by Zn, Cu, Hg and Cr. The St Thomas Harbors, as well as Gallows Bay, St Croix, were moderately to heavily polluted by Cu, Zn and Pb. Mangrove Lagoon and Bønnø Bay, St Thomas, were anomalously high in Ni (765 ppm) in sediment, and in Hg (2.5 ppb) in seawater, respectively. Maximum levels off St John were generally one or more orders of magnitude below those of the other two islands.

Very low toxic concentrations were found at the St Croix STP outfall. Although toxics at the St Thomas STP outfall showed higher concentrations, they were well below levels found both at other USVI sites and at other sewage disposal areas off US mainland coasts. Concentrations of trace elements in sediments and waters near the VAPA desalination plants in St Thomas and St Croix were low to moderate.

Except for Ni, very poor correlations were found between trace elements in marine sediments and in adjacent rocks and soils. Most of the elevated levels of Cu and Zn are attributed to boat operations and marinas. Distribution of Hg and Pb shows some evidence of atmospheric input.

Comparison with USEPA toxicity criteria indicates little need for concern with levels of Cd, Cr and Zn in USVI marine sediments and seawater, while Hg, Se, Ni and As in USVI waters generally appear to exceed USEPA criteria.

## PRECAMBRIAN ROCKS IN THE SOUTHERN EDGE OF THE CARIBBEAN PLATE, VENEZUELA

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The Coast Range of northern Venezuela is the most important feature of the southern Caribbean plate margin. The oldest reported rocks (Rb/Sr isochrons) are the Sebastopol Complex (420 Ma, Hurley & Hess, 1972) and the Guarema Granite (403 Ma, Urbani, 1983).

The metasedimentary rocks of the Caracas Group (Las Brisas and Las Mercedes formations) are the more extensively exposed and have paleontological ages of Late Jurassic - Early Cretaceous (Urbani, 1982). The core of the Coast Range is in part formed by granitic gneisses of the Peña de Mora Formation, previously considered to be equivalent in age with Las Brisas Formation.

Three samples of the Peña de Mora augengneiss from the type locality and Chichiriviche (location map in Urbani & Ostos, 1989) produce the following Rb/Sr isochron:

Sample	ppm Rb	ppm Sr	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$
PM-86-1	227.4	106.9	6.269	0.84784±0.00012
PM-86-2	227.0	83.9	7.940	0.89125±0.00014
PM-86-3	155.4	162.1	2.793	0.77486±0.00012

$^{87}\text{Sr}/^{86}\text{Sr} (t) = 0.71103 \pm 0.00734$ , best slope  $0.02240 \pm 0.00121$  that allows to calculate an Early Proterozoic age of  $1560 \pm 83$  Ma.

Rocks this old have never been previously reported in the Coast Range and introduces a new element for the interpretation of the tectonic evolution of the southern edge of the Caribbean plate and reinforces the criteria about such evolution given in Navarro et al. (1987).

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# TECTONIC AFFINITY OF MAFIC ROCKS FROM THE CARIBBEAN MOUNTAINS SYSTEM, VENEZUELA

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The Caribbean Mountains System of Venezuela consists from north to south of the following four east-west trending belts: Cordillera de la Costa Belt (CC), Caucagua-El Tinaco Belt (CT), Paracotos Belt, and Villa de Cura Belt (VC). A petrologic and geochemical study of mafic rocks in these belts was undertaken to determine the tectonic setting of these rocks and their significance with respect to the interaction of the Caribbean and South American lithospheric plates.

Major- and trace-element abundances of thirty-eight (38) samples and rare-earth element (REE) abundances of five (5) samples from the CC were analyzed. These samples were taken from the high P/T metamorphic belt of the CC. All discrimination diagrams suggest that these rocks formed in a mid-oceanic ridge or marginal basin environment (MORB).

Ten (10) hornblende gneiss samples from the CT were analyzed for major- and trace-element abundances, and three (3) for REE abundances. The major- and trace-element contents are typical of tholeiites; trace-element discrimination diagrams suggest a volcanic arc affinity, and the REE patterns indicate association with an Andean-type magmatic arc.

Major- and trace-element abundances of thirty-two (32) metagabbros from the VC were analyzed; twenty-five (25) from the high P/T metamorphic Villa de Cura Group and seven (7) from the Dos Hermanas Formation. REE abundances were measured in four (4) samples from the Villa de Cura Group. The trace-element abundances and discrimination diagrams of the high P/T rocks suggest that these rocks were MORB's; the REE contents and patterns are inconclusive. The major and trace elements of the Dos Hermanas metagabbros indicate that they are tholeiites and have formed in a volcanic island arc setting.

Two tectonic models will be proposed. In the first, the entire Caribbean Mountains System is allochthonous and was formed far to the west. In the second the VC is proposed to be parautochthonous.

## THE TINAQUILLO PERIDOTITE COMPLEX, VENEZUELA

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Both the Tinaquillo Peridotite Complex (TPC) and the Tinaco Complex (TC) are part of the Caucagua-El Tinaco Belt. The TPC consists of approximately 70% harzburgite, 20% dunite, and 10% metagabbro. Traditionally, it was thought that the TPC intruded the TC as a crystal mush and that the metagabbro bodies were xenoliths of the TC. Major- and trace-element abundances of twelve and rare-earth element (REE) abundances of three metagabbro samples from the TPC were analyzed. The  $TiO_2$  and trace-element abundances are characteristic of mid-oceanic ridge or marginal basin tholeiites (MORB). Normalized REE patterns of the TPC metagabbros are flat but for positive Eu-anomalies; they also are characteristic of MORB's and are similar to the REE patterns of gabbros of the Semali ophiolite. Major- and trace-element abundances of ten and REE abundances of four metagabbros from the TC were analyzed. The  $TiO_2$  contents are characteristic of volcanic arc basalts. The REE patterns show a light REE enrichment similar to basalts of Andean-type margins. Thus, the metagabbros of the TPC are not xenoliths of the TC. Instead, the TPC may be an ophiolite sutured to the TC during pre-Cretaceous time.

Microprobe analyses of pyroxenes of the TPC peridotites indicate that they underwent at least two thermal events. The first event occurred at approximately 1400°C and the second at about 650°C; the first may be related to crystallization in the upper mantle; the second may be related to the tectonic juxtaposition of the TPC and TC.

The gabbros of the TC near the contact with the TPC have relict granulite facies mineralogies, which may be related to the 650°C event in the TPC. All rocks of the TPC have an intense mylonitic texture which formed during the 650°C event by oblique dextral strike-slip or oblique southeastward underthrusting along the east-west striking, south dipping tectonic contact of the TPC and TC.

# INTERPRETACION DE LOS DATOS GEOFISICOS CON FINES DE LA CARTOGRAFIA GEOLOGO-ESTRUCTURAL DE LA REPUBLICA DE CUBA

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Se exponen los principales resultados en la interpretación geológica de los datos gravimétricos, aeromagnéticos y aerogammasspectrométricos, con fines de la cartografía geológico-estructural de la República de Cuba. Se incursiona en el problema de la naturaleza geológica de las principales fuentes de anomalías gravimagnéticas residuales y, aerogammasspectrométricas. Como resultado, se establece el carácter, fundamentalmente, rocoso de las primeras y, la probable vinculación de las últimas con la concentración de distintos óxidos en la parte superior de la corteza de intemperismo (suelos), a consecuencia de su evolución en las condiciones de clima tropical. En base a la regionalización conjunta (visual) de los campos gravitatorio y aeromagnético se confecciona un esquema interpretativo geológico-estructural de la República de Cuba; se delimitan las principales unidades o bloques geológico-geofísicos y, se comenta, especulativamente, sobre su posible naturaleza y relación. Finalmente, se aborda la identificación de los complejos estructuro-rocosos reconocidos en el esquema anterior, con sus homólogos estructuro-metalogénicos.

## LA CONSTITUCION GEOLOGICA DEL MACIZO ISLA DE LA JUVENTUD Y SU METALOGENIA ENDOGENA VINCULADA AL MAGMATISMO ACIDO.

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Se argumenta la solución teórica del problema acerca del vínculo entre la estructura dómica regional más joven, superpuesta al cuadro de multiplegamiento y metamorfismo de las secuencias del macizo, y el desarrollo del magmatismo ácido y su metalogénia asociada en la región. Como resultado, se establece que, probablemente, a consecuencia del proceso de formación y evolución estructural del domo, tuvo lugar el empujamiento de pequeños plutones graníticos ( $50-100 \text{ Km}^2$ ), localizados en la intersección del sistema radial de grietas del domo con el sistema anular de fracturas profundas que lo delimita, a través del cual, presumiblemente, penetraron los fundidos anatóxicos. A partir de sus apófisis subvolcánicas diferenciadas, tuvo lugar, al parecer, la telescopia de las intrusiones fisurales y de la mineralización, fundamentalmente, dentro del sistema radial de grietas. Basado en un mecanismo de herencia metalogénica, se supone que los plutones graníticos formados condujeron a concentraciones minerales, sólo donde éstos sobreyacen a zonas mineralizadas preexistentes y; que la regionalización geoquímica del territorio reproduce la zonación geoquímica (y metalogénica) del basamento reelaborado.

Modelo para la evaluación de recursos potenciales (Pronóstico  $P_3$ ); consideraciones teórico-metodológicas.

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Se describe un modelo para la evaluación de recursos potenciales (pronóstico  $P_3$ ) y el procedimiento de aplicación, a ser utilizado en los casos de regiones poco exploradas, levantadas en escalas medias (1:250 000 - 1:100 000), donde no se dispone de información precisa acerca de la densidad espacial, dimensiones y, ley promedio de los depósitos de interés. El método descrito constituye una generalización del modelo de Finch y Mc Cammon (1987). Esta se fundamenta en la derivación del factor probabilístico a partir de la distribución de ocurrencias minerales en el área de estudio y; en la estimación del tonelaje de mena y de la ley del mineral útil, así como del factor de error asociado, a partir de las estadísticas correspondientes a los depósitos tipo mundial. La concepción de este modelo responde a una base teórico-metodológica de límites precisos, la cual se expone en la parte introductoria del trabajo.

ANALYSES MINÉRALOGIQUES ET PETROGENESE DES ROCHES DU VOLCANISME RECENT DE LA BASSE-TERRRE EN GUADELOUPE

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Sept échantillons représentatifs de la série magmatique du volcanisme Madeleine-Soufrière ont été choisis pour une analyse minéralogique plus approfondie. Toutes les phases minérales ont été repérées et analysées de façon à mettre en évidence l'évolution magmatologique du massif récent.

- La composition de ces phases minérales,
  - leur ordre d'apparition,
  - les calculs de températures d'équilibre,
  - l'existence ou non de certaines phases minérales à certains stades d'évolution magmatique,
  - l'observation de traces d'instabilité pour certains minéraux,
- ont permis d'aboutir à un modèle basé sur l'écagement de deux réservoirs magmatiques aux profondeurs respectives de 18-20 km et de 8-10 km évoluant chacun par cristallisation fractionnée.

En outre, ce modèle est en accord avec la répartition des foyers des séismes au niveau du massif de la Soufrière.

MINÉRALOGIE DES SUBLIMÉS FUMÉROLIENS AUX SOUFRIÈRES DE GUADELOUPE ET DE MONTERRAT

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L'analyse minéralogique par diffraction des rayons X d'échantillons de dépôts fumerolliens prélevés aux Soufrières de Guadeloupe et de Montserrat a permis d'identifier une vingtaine de minéraux sublimés dans l'environnement immédiat des événements fumerolliens.

La plupart de ces minéraux de basses températures sont des sulfates. Les minéraux les plus abondants et les plus fréquemment rencontrés sont : le gypse, l'anhydrite, les alunogènes, l'halotrichite, la calcite, les asectites, le soufre, le quartz et la pyrite.

La cristobalite est rencontrée sous les deux phases, basse et haute températures ; cette dernière phase devant appartenir au groupe des minéraux volcaniques associés par entraînement mécanique aux dépôts fumerolliens. Ces minéraux résultent pour l'essentiel de l'attaque par les gaz volcaniques riches en  $H_2S$  du matériel andésitique constituant l'encasement des dépôts étudiés ; l'action météorique pouvant jouer un rôle secondaire, le gypse étant par exemple probablement le produit de la transformation de l'anhydrite d'origine volcanique.

Eocene STRATIGRAPHICAL STUDIES, MARACAIBO BASIN, NORTHWESTERN VENEZUELA.

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Benthic foraminiferal analysis were carried out in samples (cuttings, cores) of eight wells and one outcropping section from the Maracaibo Basin, northwestern Venezuela.

The wells located across the basin, from the west to southeast, are in the La Paz, Concepcion, Sibucara, Cabinas and Ceuta oil fields; and the outcropping Eocene section is near the Misoa Anticline, eastward the Mens Grande oil field (Text-Fig.1).

The siliciclastic sequence, early Eocene - late middle Eocene in age, is formed by the Trujillo, Misoa, Pauji and Jarillal formations.

Five foraminiferal assemblages, paleobathymetrically related were distinguished: 1) Alluvial Trochammina sp. assemblage typify the Misoa Formation to the west. 2) Deltaic Trochammina - Haplophragmoides assemblage characterize the Misoa Formation in the whole studied area. 3) Nearshore Quinqueloculina - Agglutinated Foraminifera assemblage recorded at the base and at the top of the Misoa Formation, in the central and eastern studied area. 4) Inner-Mid neritic Bolivina - Siphonina umbonifera assemblage recognized at the base of the Pauji Formation and at the top of the Trujillo Formation. 5) Outer neritic/upper bathial Sigmoilopsis schlumbergeri - Textularia sagittula assemblage recognized in the Pauji Formation and locally (to the midwest of the area) in the Misoa and the Trujillo formations.

Paleobathymetric changes such as shallowing upward sequences (between the Trujillo and Misoa formations), deepening upward sequences (between the Misoa and Pauji formations), and the main changes within the Misoa Formation are related to the sediment supply and to eustatic changes of the sea level. However, local changes can be related to paleotopography and possibly to isosedimentary faulting.

Known reservoirs in the Misoa Formation and at the top of the Trujillo Formation are sand bodies deposited in the nearshore and deltaic environments then, the faunal assemblages distribution can be used to predict facies changes and consequently some sandy reservoir limits.



# STRUCTURAL INTERPRETATION OF GRAVIMETRIC AND AEROMAGNETIC DATA FROM THE SERRANIA DEL INTERIOR RANGE AND THE MATURIN BASIN (VENEZUELA).

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The eastern Serranía del Interior lies in northeastern Venezuela, south of the El Pilar dextral strike-slip fault. It represents the foreland fold and thrust belt of the eastern part of the Caribbean Chain. The Maturín Basin lies between the frontal thrust of the range and the Guyana shield.

Both the stratigraphy and the shallow structural pattern of the Serranía have been studied with data from a geological field survey. At a more regional and deeper scale we studied gravimetric and aeromagnetic data.

The Bouguer anomaly increases between Maturín (-160 mGal) and the El Pilar fault zone (0/+10 mGal). Modelling on the profile Muelle de Cariaco-Aragua de Maturín-Puerto Ordaz has enabled us to confirm the existence of a shallowing in the basement below the northern half of the range, from a thickness of ~10 km in the sedimentary cover below the Maturín Basin.

The pseudogravimetric transformation of the magnetic anomaly (induced magnetization) shows that the gravimetric and magnetic anomalies share the same origin in the crystalline basement. This is most clearly shown by the same N70 structural trends in both magnetic and gravimetric anomalies.

In addition, we see a N130 lineation in the southeastern sector. This may indicate that the Urica fault, which is seen in the sedimentary cover to the NW, has also involved the basement. However, there is no direct evidence of faulting in the sediments directly above the magnetic lineation. Instead, we propose that the Urica fault was produced by readjustment in the sedimentary cover above a preexisting discontinuity. This is in agreement with our interpretation of the northern Maturín Basin seismic data, which shows the existence of a basal detachment surface.

We finally propose that the shallowing in the basement shown by the gravimetric models is the result of a post-Miocene movement (slab elastic flexure).

Ref. : POTIE G., (1989) - La Serranía del Interior Oriental sur le transect Cumana-Urica et le Bassin de Maturín (Venezuela). Application des données géophysiques et géologiques à une interprétation structurale. Ph.D. thesis University of Brest (France), 1989, 240 pp., 95 figs., 13 pl.

# PATTERN OF FAULT AND FOLD STRUCTURES IN COASTAL PLAIN AREAS OF SOUTHERN PUERTO RICO AND CENTRAL ST. CROIX

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Subsurface geologic maps using data from over 500 coastal plain water wells in southern Puerto Rico and central St. Croix indicate that both areas are underlain by a complex series of subsurface fault or fold structures.

Puerto Rico's southern mountains are bordered by six fan-deltas that combine into a narrow (3 to 8 kilometer), but elongate (70 kilometer) coastal plain, forming a coastward thickening sequence (>500 meters) of bedded cobbles, gravel, sand and silt of Miocene (?) to Holocene age. Fan-deltas cover two northwest-trending, left-lateral wrench faults, the Río Jueyes and Esmeralda faults. Subsurface maps indicate that both faults continue to the southeast as a series of en echelon faults, and combine with northeast-trending cross faults to form a complex of horst and graben structures. Uplifted blocks lie at the discontinuous end of major strike-slip faults and graben structures lie between them. To the southwest, an unnamed fault lies parallel to the Río Jueyes and Esmeralda faults, and extends west-northwest nearly to the western edge of the coastal plain margin. The unnamed fault links with several other faults that strike northeast. These faults, in combination, form the landward edge of the Ponce basin.

A structure contour map of the Jealousy Formation of Oligocene to Miocene age, suggests that several fault block structures vertically displace St. Croix's central carbonate coastal plain sequence. Faults mapped in the subsurface strike in two directions. One group of faults strikes to the northeast and displaces coastal plain strata adjacent to the Northside Range. These faults are complemented by faults that strike northwest. An uplifted fault block or fold structure in the northeastern part of the coastal plain seems to lie in the compressional quadrant of a strike-slip fault. A downdropped block in the south central part of St. Croix lies in the tensional quadrant.

A pull-apart basin tectonic framework is postulated to explain horst and graben structures in southern Puerto Rico. The pattern and orientation of subsurface faults and fold structure that underlie central St. Croix are suggestive of extension and contraction along a buried left-lateral strike-slip fault.

# PROBLEMAS DE LA GEODINAMICA DE CUBA

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La naturaleza tectónica de Cuba muestra una gran complejidad y heterogeneidad. Los procesos de colisión y de destrucción tuvieron un carácter diferente y asincrónico en diferentes segmentos de Cuba. En el Segmento Central está representada la serie lateral más completa de elementos estructurales de diferentes zonas. Aquí, la formación de la estructura plegada alpina es el resultado de dos colisiones diferentes: Campaniano y Eoceno Inferior-Medio. La primera se debió al choque de un fragmento (desprendido y transportado hacia el Norte) del margen continental de América del Sur, con el arco insular surgido en la paleocuenca del Caribe en el límite Jurásico-Cretácico. La causa de la primera colisión fue la subducción (con buzamiento al Norte) de la corteza oceánica de la depresión meridional, bajo el borde sur del arco volcánico y la consecuencia deriva hacia el norte del fragmento de América del Sur. Como resultado de esta colisión, cesó la subducción y se formó el arco insular protocubano, en cuyos taludes se acumularon, a partir del Campaniano-Maestrichtiano, complejos molásicos y carbonatado-terrigenos. Esta colisión provocó el "salto" de la zona de subducción al borde norte del arco protocubano, con buzamiento al Sur. De esta manera, comenzó el proceso de absorción de la corteza oceánica de la depresión septentrional, produciéndose un acercamiento rápido del continente norteamericano con el arco insular, completándose en el Eoceno Inferior-Medio su colisión y la obducción de los fragmentos alóctonos de la depresión suboceánica y del arco insular protocubano, sobre el margen continental. En el Segmento Occidental (al oeste de la Falla Pinar) el carácter de los procesos geodinámicos fue diferente. Aquí en el Paleoceno Superior-Eoceno Inferior-Medio, ocurrieron la colisión directa del fragmento continental suramericano y el margen continental norteamericano. La colisión parece ser la única que se produjo en este segmento y provocó una complicada estructural de sobrecolismientos en los complejos de la cobertura sedimentaria de ambos márgenes.

En el Segmento Oriental los procesos transcurrieron de una forma completamente diferente. Aquí, se produjo también el choque del arco insular cretácico con el margen continental norteamericano, el cual provocó el cabalgamiento en dirección norte de los complejos del primero. Además de esto, al final del Cretácico Superior (Maastichtiano-Paleoceno) se produjo la escisión del arco insular, a lo largo de la línea Cauto-Nipe, produciéndose un movimiento divergente (al noroeste y al sureste) de las masas rocosas. Al norte ocurrió la colisión de los fragmentos del arco volcánico con el margen continental norteamericano, mientras que en el Sur se produjo el apilamiento tectónico de los complejos del primero, los cuales constituyeron el basemento plegado del arco volcánico del Paleógeno Temprano de Sierra Maestra-Caimán. En el centro de la zona de distensión, posiblemente sobre un diapiro del manto, surgió una depresión riftogénica suboceánica de corto período de desarrollo, al parecer relacionada genéticamente con la Cuenca de Yucatán.

# WHITING SEDIMENT: BIOLOGICALLY INDUCED NON-SKELETAL PRECIPITATION OF ARAGONITE

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The origin of whiting sediments have been a controversial subject for decades. Although both skeletal and non-skeletal origins have been proposed, none of the evidence thus far has been conclusive. Data collected from several whittings from west of Andros Island, Bahamas in October 1987 and August 1988 suggest that these aragonite laden waters may be the result of high organic content in supersaturated carbonate waters.

During the August cruise, a number of whiting samples were collected and immediately preserved in glutaraldehyde. Scanning and transmission electron microscopy of preserved and non-preserved samples clearly demonstrates a relationship to cellular organics and aragonite crystals. SEM analysis of preserved whiting sediment reveals the presence of clumped spheres of randomly oriented aragonite needles ranging in size from 15-30 microns in diameter. TEM of the samples shows that cells and organics in varying stages of degradation are associated with aragonite needles. Aragonite crystals exhibit a random array, having both perpendicular and parallel orientations to the organic membranes. This type of mineralization implies a biologically-induced precipitation as opposed to a biologically-controlled or matrix mediated mineralization. Further data on the biochemical nature of the organics associated with the whittings indicate the presence of highly negatively charged proteins and macromolecules on which calcium carbonate may precipitate.

These data suggest that some of the Bahama Banks precipitation of aragonite needles may be partially induced by the highly charged microenvironment created by cells in various stages of growth and degradation. Whiting sediments appear to be biologically induced, but of a non-skeletal origin. This mechanism has far reaching implications in the production of lime mud throughout the geological record.

# IMPERFORATE LARGER FORAMINIFERA FROM THE OLIGOCENE OF JAMAICA

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Assemblages of larger foraminifera in platform carbonates from central and eastern Jamaica contain *Praerhapydionina* delicate, as well as species of *Archaias*, *Miosorites* and other peneropliform genera, from levels correlated with the Oligocene Browns Town Formation. The age and significance of the assemblages are briefly discussed.

# PALEOCENE LARGER FORAMINIFERA FROM EASTERN JAMAICA

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Species of *Ranikothalia* and *Discocyclina*, previously reported from the Paleocene Nonsuch Formation of northeastern Jamaica, are described and illustrated.

# SIGNIFICANCE OF GEOTHERMAL GRADIENTS IN PETROLEUM EXPLORATION IN TRINIDAD

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The correlation between positive geothermal anomalies and the occurrence of hydrocarbons is based on the premise that water is the major agent of both hydrocarbon migration and heat transfer in sedimentary basins, and suggests a genetic link between geothermal gradients, hydrodynamics and hydrocarbon occurrences. This association has generated growing interest in geothermal studies in relation to the occurrence of petroleum deposits and the importance of the temperature history experienced by the source rock in the maturation process.

Geothermal gradients were derived from bottom hole temperatures recorded on electric logs from 250 exploratory and development wells drilled over Trinidad, including the Gulf of Paria and the North Coast and East Coast marine areas. A study was undertaken to determine the temperature regimes, to identify and map the depth range of the oil window in various areas and to delimit the zones of heavy (biodegraded) oils. An iso-geothermal gradient map of Trinidad, showing local and regional variations in heat flow, is presented.

Geothermal gradients over Trinidad vary between 0.9°F and 2.0°F per 100' (17°C and 36°C per Km), rarely exceeding 1.5°F/100' (28°C/Km), and are comparable to the worldwide average of 25°C/Km. These variations are related primarily to: (i) position of basement (heat source) with respect to overlying sediments; (ii) difference in vertical and lateral thermal conductivity of the rocks due to lithologic variation; and (iii) effects of water moving through the sedimentary section.

Caribbean Conference Abstract for Rosencrantz. Oral Presentation

# TWO-PART CONVERGENCE ALONG THE CUBAN OROGENIC BELT: OBSERVATIONS AND IMPLICATIONS

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The Cuban orogenic belt is commonly considered as arising from the convergence and collision between a northward moving Antilles volcanic arc and a stable Bahamas carbonate platform in Eocene time. However, Cuban stratigraphy and structure suggest that the belt was assembled in two stages, one in the Late Cretaceous and the second in the Early to Middle Eocene. During the Cretaceous, Cuban Zaza Zone volcanic rocks accumulated as an island arc over a north-dipping subduction zone located south of the arc. Remnants of this subduction zone include a buried trench along the southeast margin of Cuba and the metamorphic shear zone mapped along the northern edge of the Escambray massif. Campanian to Maastrichtian radiometric cooling ages of plutonic and related metamorphic rocks north of this suture, and of blueschist minerals located within the suture, suggest that subduction had ceased by this time. Arc rocks were extensively eroded during the Maastrichtian, with local exposure of basal ophiolites. Crust south of this suture, within the Yucatan Basin, includes the Escambray and Isle of Pines metamorphic massifs and the thickened oceanic crust of the Cayman Rise, the presence of which probably contributed to north-dipping subduction stoppage. Post-Maastrichtian North American-Caribbean convergence took place along a south-dipping thrust zone located north of the arc. The overthrust sequence, consisting of Cretaceous arc and Caribbean Basin (Tethys) sediments and basement, obducted onto the Bahamas platform during the Middle Eocene. Platform sediments show little evidence of overthrusting until Upper Paleocene time. Wells drilled in the Havana area penetrate series of platform sequence duplexes emplaced during Late Paleocene to Early Eocene time. Dated melange rocks in central and western Cuban indicate that arc rocks thrust over, and deformed, underlying sediments between Early and Middle Eocene time. During the northward movement of the overthrust plate, a small pull-apart ocean basin, similar to the present-day Cayman Trough, developed within the plate along its western, strike-slip margin adjacent to the Yucatan platform.

Caribbean Conference Abstract for John G. Slater. Oral Presentation

# THE CAYMAN TROUGH: AN ASSESSMENT

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The opening of the Cayman Trough has long been used as a measure of the displacement of the Caribbean plate relative to the North American plate and, indirectly, relative to the South American plate. This measure is not absolute as once thought, owing to the observation that the core of the Caribbean plate, as represented by the Colombian and Venezuelan Basins, is separated from the North American plate by one or more EW trending transcurrent fault zones located south of the trough. Nevertheless, the history of trough opening provides important clues as to the age and duration of tectonic events within the northern Caribbean. However, this focus on the trough as an element of tectonic reconstruction tends to obscure the fact that the trough in itself displays several aspects which present a number of interesting problems.

For instance, the Cayman Trough provides the opportunity to study the full evolution of what might be considered a "mature" pull-apart basin. The regional tectonics of the northern Caribbean suggest that the trough originated during the Eocene as a pull-apart along the developing EW trending North American-Caribbean transform shear zone. This is supported by observations that rift blocks at the eastern and western margins of the trough lie oblique to the bounding strike-slip faults, with fault patterns similar to those seen within pull-aparts developed on smaller scales and similar to those documented by experimental work. In contrast, magnetic anomalies and crustal faults originating by seafloor spreading within the trough trend at right angles to the boundary faults. The transition between the rifted margin and oceanic crust is abrupt, with seafloor spreading faults apparently truncating those of the rifted margin.

Another interesting aspect of the Cayman Trough is that its opening direction is tightly constrained by the bounding transforms. The basin opened along a set of "railroad tracks", so to speak, and opening can be reconstructed with an exact match of its conjugate rift margins. This has important implications with regard to rifting sequence and to the nature of the initiation of seafloor spreading within rifted crust.

The Cayman Trough offers the opportunity to examine lithospheric cooling under conditions other than those of deep ocean basins. Measurements of crustal depth and heat flow within the trough show that it is too deep and too cold relative to crustal age as determined from marine magnetic anomalies and regional tectonics. This suggests that lithospheric cooling within the trough is strongly affected by heat loss lateral to the trough, toward the older, colder lithospheric masses of the bounding Nicaragua and Cayman rises. Measurements of basement depth and heat flow within the trough show good correlation to depth and heat flow predicted by small ocean basin cooling models which include lateral as well as vertical cooling of accreting lithosphere. This difference of cooling history, set against probable differences in seafloor crustal composition and structure, can provide additional insight into the mechanics of ocean crust formation.

# LATE CRETACEOUS SYNOROGENIC FLYSCH OF EASTERN GUATEMALA - THE SEPUR FORMATION

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Over 2,700 meters of Late Campanian to Maastrichtian flysch of the Sepur Formation overlie the continental Yucatan (Maya) Block in eastern Guatemala. The flysch and underlying units are folded and thrust by post-Maastrichtian/pre-Miocene compression attributed to the collision of the Maya Block with an island arc or the Chortis microcontinent.

Clasts in Sepur Formation sandstones and channelized debris flow conglomerates indicate provenance from volcanic, carbonate and ophiolitic terranes. Crystalline "continental" basement clasts are notably rare in eastern Guatemala.

The thick flysch sequence north of the suture zone is diachronous along strike: Late Cretaceous in eastern Guatemala, Paleocene-Eocene in western Guatemala, and Late Cretaceous through Neogene in Chiapas, Mexico. Clast lithologies in the flysch suggest increasing involvement of continental basement westward along the suture trend.

# EVOLUTION OF THE HYPOTHESES ABOUT THE ORIGIN OF THE CARIBBEAN

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In general, it can be said that geological research in the Caribbean proceeded in three stages: an initial stage (19th century) of general descriptions; a later stage of reconnaissance, in part oriented by economic motivations; and a final stage of detailed and systematic studies. The general hypotheses on the origin and evolution of the Caribbean can be subdivided into two types: static ones and dynamic ones. The static hypotheses considered that the Caribbean was a submerged continent or a permanent oceanic basin. The dynamic hypotheses can be subdivided into those that do not take into account continental drift, and those that do. Among the first, the most important one is the tectogene hypothesis (postulated by Harry Hess), a crustal zone that is folded downward, originating a negative gravity anomaly, and orogenic, volcanic, and seismic activity. Among the hypotheses that take into account continental drift, there are those that preceded the hypothesis of plate tectonics, and those that include it. The principal hypothesis that does not include plate tectonics, tries to explain the origin of the Caribbean by sea-floor spreading, from a spreading center located between North and South America. Among the hypotheses that include plate tectonics, one can differentiate between those that postulate an autochthonous origin of the Caribbean, and those that derive it from far away, for example from the Pacific Ocean. A review of the different hypotheses indicates that those that are based on plate tectonics have a similar basis and show a certain refinement with time. On the other hand, those that postulate an autochthonous origin have very diverse bases and show no refinement with time. In general, scientific research tends to progressively increase the amount and quality of data, in order to reduce to a minimum the prejudices of those who interpret them. In the geologic study of the Caribbean, this has been difficult, in large part due to the proliferation of models to explain its origin and evolution. The modern paradigm of geology, plate tectonics, was developed before sufficient data existed to generate an acceptable model for the Caribbean, which was also in accord with the paradigm. The geologic interpretation of the Caribbean began over a century ago; therefore, its history is also a summarized history of geology since the beginning of the century.

# ORIGIN OF THE LESSER ANTILLEAN ISLAND ARC: DATA FROM REPTILES AND AMPHIBIANS

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Data on the ecology, systematics, and biogeography of *Anolis* lizards, combined with that on other reptiles and amphibians in the eastern Caribbean, suggest that:

1. The northeastern and southeastern Caribbean have had distinct geologic histories. The line separating these provinces starts between Dominica and Martinique and extends southwest to between Curacao and Bonaire.
2. Within the northeastern province, material in the Guadeloupe-Dominica region has split off from Puerto Rico. The fauna of Guadeloupe and Dominica has had a primarily vicariant origin (i.e., consists of the descendants of populations that were on Proto-Guadeloupe at the time of its original fragmentation from Puerto Rico). This region has then served as a biological source for the younger islands north of Guadeloupe up to the Anegada Passage. Propagules have come north from Guadeloupe by over-water dispersal, in accordance with the prevailing currents.
3. Within the southeastern province, St. Lucia, La Blanquilla and Bonaire seem to be members of a former island arc that was "upstream" of the eastward-moving Caribbean plate. Collision with this island arc resulted in the insertion of St. Lucia between Martinique and St. Vincent, while La Blanquilla and Bonaire were pushed down onto the Venezuelan shelf. The oceanic islands of the southeastern province thus consist of at least four classes of terranes: Curacao—related to Grand Cayman; Bonaire and La Blanquilla—related to St. Lucia; the triplet consisting of Martinique, St. Vincent, and Grenada; and Barbados—an exposed piece of accretionary prism that has formed *in situ* and been colonized recently through local over-water dispersal.

# REGIONAL STRUCTURAL AND VOLCANIC EVENTS WITHIN THE COTUI LIMESTONE-SABANA GRANDE CONTACT INTERVAL (LATE CAMPANIAN), SOUTHWEST PUERTO RICO

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The Campanian Cotui Limestone represents a transgressive carbonate platform which occurs between the Guanajibo and Leñas valleys, Southwest Puerto Rico Terrains. The Cotui disconformably overlies the Lajas Formation (porphyritic lava, minor tuff) and is conformably overlain by the Late Campanian-Maastrichtian Sabana Grande Formation (volcaniclastic conglomerates, sandstones, siltstones, minor limestone lenses). The Cotui Limestone is divided into a lower, thick-bedded, gray mudstone and grainstone containing rudistid and stromatopore frameworks, and an upper white-light gray massive grainstone/packstone. Carbonate deposition across the Cotui platform is terminated by rapid inundation of coarse volcanic and limestone breccias in a volcaniclastic matrix, and shallow marine mass flow deposits, suggesting a major structural/volcanic event. The co-occurrence of *Purania curasavica* and *Barrellia monilifera* in the uppermost Cotui Limestone indicates a Late Campanian age. *Barrellia monilifera* in limestone breccias of the basal Sabana Grande Formation suggests a Late Campanian-Early Maastrichtian age. New field data from the Escuela Padre Rufo area, San German Quadrangle, reveals several episodes of normal faulting during uppermost Cotui-lowermost Sabana Grande deposition associated with major increases in size and amount of volcaniclastic detritus across the southwestern platform. The following series of events were noted: 1) Formation of a half-graben during latest Cotui time; 2) slump of thin carbonate mudstones with flow structures containing large angular volcanic blocks into the graben; 3) temporary quiescence; Cotui Limestone became lithified with early marine cements; 4) renewed movement on the bounding half-graben fault associated with rapid increase in volcanism; mass flow of volcaniclastic debris into the graben incorporating angular blocks of Cotui Limestone; deposition of the Cotui-Sabana Grande transition sediments continued uninterrupted on the north block of the graben; 5) formation of a shallow marine channel within the graben, rounding volcaniclastic pebbles and partially rounding limestone clasts; thin conglomerates spilled over onto the stable block; 6) deposition of shallow marine volcaniclastic sands over the entire area, smoothing fault and channel topography; 7) development of a second normal fault cutting lower Sabana Grande sandstone; the fault dip opposes that of the first fault; and 8) renewal of volcaniclastic sand deposition. This major Campanian event produced tectonic faults, rapid initiation of volcanism, and spread of debris flows over much of southwestern Puerto Rico.

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The Caribbean Geological Conferences began in 1955 in Antigua with a meeting of only 37 delegates who attended as representatives mainly from the British territories. The series has run without break since then with a three year interval between meetings. The second gathering was held in Puerto Rico with still only 55 delegates. From then onwards, the conferences have been widely advertised and have attracted a broad spectrum of Caribbean geologists and kindred spirits. Conferences today can expect anything up to 200 delegates.

Right from the start, the series has been supported by workers domiciled in the region together with interested participants from further afield who did much, particularly in the early days, to make the connection with academic institutions in North America and Europe. One thinks immediately of Harry Hess from Princeton who had so many students writing theses in the region that, in those heady days, no rum shop from St. Croix to Barquisimeto via Mayagüez was safe from them. Now these students have sent their students who are busy trying to overturn the work of their own masters no doubt.

If the actors have changed, so has the geology - or at least the interpretation of it. At the time of the first meeting the physicists were still telling us there was no way that they would sanction crust sliding about in such a cavalier fashion as the drifters wanted. There was thus still some surreptitious use of land bridges by harassed stratigraphers and palaeontologists.

It was just at the time of the Third Conference in 1962 that the hypothesis of sea floor spreading was first being voiced. In fact, Professor Hess excused his absence from the Fourth Conference because he had to go to Europe to defend his ideas which were still treated with caution if not with disdain by some.

So, the Atlantic was finally opened with some panache, or at least the north and south, but what of the middle? What should be done with the Caribbean? The results from Leg 15 of the Deep Sea Drilling Project were reported at the Sixth Conference in 1971 and this gave the first direct evidence of what lay beneath, or at least, what lay at the top of what lay beneath. At the same conference we were given the first plate model for the development of the Caribbean. This was hot off the press and was to be followed by many others.

Today we know everything, of course. But do we? Perhaps we should go on for a while longer to clean up a few of the new problems that the old answers have created. Where better than at a Caribbean Geological Conference within reach of the sharp tongues of our peers.

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Deep continuous cores taken by the Water Resources Division of the US Geological Survey show that during the late Oligocene and part of the Miocene, the marine shelf (ramp) of northern Puerto Rico was divided into at least four "sub-basins", each with a different depositional history. Vertical and lateral variations in stratigraphy apparently reflect relative sea-level fluctuations resulting from both structural movements and eustatic changes.

**L. Oligocene transgression followed by minor regression** - A. NW shelf: sand and mud (San Sebastian Fm) interfinger eastward with miliolid-soritic carbonate mud (Cibao Fm). B. W-central shelf: sand and mud (San Sebastian) up into large-foam and red-algae carbonate mud and sand and coral patch reefs (Lares Fm). C. E-central shelf: same as B. D. NE shelf: same as C.

**L. Oligocene - E. Miocene transgression** - A: marl and carbonate mud with sand and mud (Cibao). B: large-foam red-algae carbonate sand and muddy sand (Montebello Member of Cibao). C: clay and marl with planktonic fossils ("Mudstone Unit") in relatively deep basin (graben?). D: like B with terrigenous sand and mud.

**E. Miocene regression** - A: quartz-sandy miliolid-soritic carbonate mud (Cibao); possible subaerial exposure in westernmost part. B: quartz-sandy miliolid-soritic carbonate mud and caliche (Cibao). C: like B going into sand and gravel updip. D: skeletal carbonate mud (Cibao).

**M. Miocene transgression** - A: subaerial exposure? (Los Puertos Fm absent?). B: red-algae miliolid-soritic sand with corals (Los Puertos). C: like B. D: carbonate sand (Los Puertos) going E into terrigenous sand (Mucaronas).

**M. Miocene regression** - A: subaerial exposure? B: sand and mud and miliolid carbonate mud and caliche (Los Puertos); karst in eastern part (uplifted block?) C-D: miliolid-soritic red-algae sand (Los Puertos/Aymamon).

**M. Miocene transgression** - A-D: red-algae benthic foram carbonate sand and sandy mud with corals (Aymamon).

**L. Miocene regression** - A-D: subaerial exposure

**E. Pliocene transgression** - A-D?: planktonic-foram chalk (Quebradillas Fm).

#### 12th Caribbean Geological Conference St. Croix USVI

#### COMBINED RADAR AND GLORIA MOSAICS OF PUERTO RICO, THE U.S. VIRGIN ISLANDS, AND SURROUNDING DEEP OCEAN AREAS: TECTONIC INTERPRETATIONS

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The first high-resolution, geometrically controlled side-looking airborne radar (SLAR) mosaic of Puerto Rico and the U.S. Virgin Islands (USVI's) has been combined with the GLORIA long-range sidescan-sonar mosaic of the surrounding deep ocean areas to provide a unique view of a section of the northern Caribbean plate boundary zone. The GLORIA data provide a reconnaissance view of the structural and bathymetric features of the sea floor; the SLAR data penetrate the persistent cloud cover and dense vegetation that obscure aerial views of the geologic structures and physiographic terrains of the islands. The combined mosaics allow us to map structures across the land-sea boundary and to infer correlations between geomorphic features on land and in the submarine environment.

Puerto Rico and the USVI's lie within a 400-km-wide plate boundary zone between the Caribbean plate and the North American plate. The sense of motion between the two plates is now mainly left-lateral strike-slip, although north-south convergence and active subduction occurred here until about Eocene time. The northern extent of this plate boundary zone is defined by the Puerto Rico Trench. Its sediment-covered floor is clearly visible in the GLORIA mosaic, as are several long, slightly sinuous, east-trending, strike-slip faults. These faults lie in the forearc region between the base of the northern insular slope and the trench floor and presumably accommodate much of the present-day plate motion. The radar mosaic of the Cretaceous and early Tertiary crystalline core of Puerto Rico exhibits lineaments trending approximately N72°W. These lineaments are not discernible in the middle and late Tertiary sedimentary units that flank the older core, which implies that they are relics of the older convergent regime rather than of the more recent strike-slip regime. The Great Southern Fault trends somewhat more north of west (N55°W) than the other lineaments, which it appears to truncate. This suggests that the fault postdates the other lineaments. The GLORIA mosaic of the Mona Canyon area shows fault traces that have the same orientation as the Great Southern Fault. The southern edge of the plate boundary zone is marked by the Muertos Trough, where the GLORIA mosaic reveals a band of deformed sediments at the base of the insular slope.

#### LATE JURASSIC TO LATE CRETACEOUS DEVELOPMENT OF ISLAND ARC CRUST IN SOUTHWESTERN PUERTO RICO

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Three stages of crustal development can be recognized in Southwest Puerto Rico based on fossil assemblages, radiometric ages, geochemistry, and petrology. The first two stages are preserved in the rocks that occur as rafts in the serpentinite of the Bermeja Complex. The third stage unconformably overlies the Bermeja Complex. The first stage is represented by abyssal ocean floor rocks, the second stage formed at bathyal depths due to crustal thickening by island arc or ocean floor volcanism. The third stage represents island arc rocks formed in neritic and subaerial environments following deformation and erosion of the stages one and two. The Bermeja Complex consists of serpentinite, metamorphosed basaltic rocks, cherts, and associated silicified volcanoclastics. The basaltic rocks range in metamorphic grade from weakly metamorphosed prehnite-bearing rocks, through greenstones, to amphibolites. Radiolarian assemblages suggest that stage one is Kimmeridgian - Tithonian, and of northern Tethyan to Boreal paleogeographic origin; stage two is Hauterivian - Aptian; and stage three cherts formed from the Cenomanian to Campanian in the Tethyan Realm. Major, trace, and REE data fail to distinguish between an ocean floor and island arc origin for the basaltic metamorphic rocks. Clinopyroxene compositions for the greenstones, dikes, and two pyroxene gabbro suggest an island arc origin. Radiometric ages indicate a Hauterivian to Alban age for these rocks, corresponding to the second chert forming period. The third chert forming period is coeval with the intrusion of the Mayaguez Porphyry diorite, and its associated island arc volcanic series. These volcanics were probably subaerial and are partly covered by Santonian and Campanian reef and shelf limestones.

Volcaniclastic sedimentation pattern and subsequent faunal breaks:  
An example from the Upper Cretaceous of Jamaica.

by

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The Upper Cretaceous succession in Jamaica is linked to small scale erosional windows exposing sedimentary rocks of Campanian to Maastrichtian age. The carbonate shoal/volcaniclastic sedimentation pattern is related to tectonic uplift and subsidence of the constricted Caribbean Plate producing clastic sequences and carbonate mounds in a close spatial relationship. Repetitive sequences of sandstones and siltstones are attributed to turbidite/submarine fan sedimentation. Coarse conglomerates and bioclastic limestones are interpreted as near-shore deposits and shallow water rudist reefs, respectively. The rock formations of the Campanian to Middle Maastrichtian times are comparable to facies associations of submarine fan models. Sediment gravity flow mechanics distribute shelf sediments through feeder channels into a deep-water environment, where they are laid down as submarine fans in an arc-related sedimentary basin.

The Middle and Upper Maastrichtian rock record is characterized by rudist build-ups and intercalated fossiliferous shales containing other bivalves, gastropods, solitary corals and echinoids with a near shore to shelf edge affinity. Rudists vanish in the Middle Maastrichtian to the expense of oysters and other fossil groups. The abrupt change from rudist-dominated fossil assemblages to oyster communities cannot be explained by catastrophic events or unconformable contacts. It is suggested that changing substrate conditions in a shallowing upward sequence were responsible for the Middle Maastrichtian faunal breaks in Jamaica.

GEOCHEMICAL COMPARISON OF CRETACEOUS BASALTS FROM THE CARIBBEAN, PACIFIC, AND ATLANTIC PROVINCES: ATLANTIC AFFINITY OF THE CARIBBEAN PLATE ?

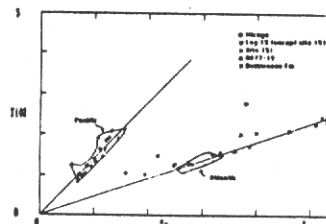
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Major, minor and trace element compositions of rocks of the Cretaceous "basaltic province" of Donnelly are compared with basalts of similar age from Leg 51-53 (Atlantic) and Site 462 (Nauru Basin, Pacific). Data selection from equivalent Pacific and Atlantic MORBs is based on (1) data availability, (2) quality of the data, (3) appropriate age, and (4) basalts with  $SiO_2 = 48.5 - 51\%$ . The Caribbean data base includes basalts or their metamorphic equivalents from Leg 15 (Caribbean sea floor), Bahi/Dunrobin Fm. and Mt. Hibernia Schists (Jamaica), Dumisseau Fm. (Haiti), Duarte Complex (Dominican Republic), Sans Souci Fm. (Trinidad), and Nicoya Complex (Costa Rica). The Duarte Complex metabasalts appear to be generally different from the others and will not be considered here as a part of this group. The Sans Souci, Nicoya, Mt. Hibernia, lower Dumisseau (LREE-depleted, Ti-poor) and Leg 15 (except Site 151) rocks are very similar to each other. The upper Dumisseau (LREE-enriched, Ti-rich) and Site 151 basalts are similar to each other and are more differentiated than the other rocks of the Caribbean province.

Cretaceous basalts from Leg 51-53 (Atlantic) are distinct from Site 462 (Nauru Basin, Pacific) in several binary element-element plots. The compositional fields of the Caribbean rocks overlap those of the Pacific and Atlantic in most plots except a  $TiO_2$ -Sm plot where the Atlantic and Caribbean groups overlap and are fitted by a straight line characterized by a  $TiO_2/Sm$  ratio that is distinct from the Pacific ratio (see fig. below).

Given the limited nature of the data from the Pacific, our tentative conclusions are: (1) the compositions of the Caribbean rocks support Donnelly's concept of a Caribbean Cretaceous Basaltic Province (Duarte Complex excluded) (2) basalts of the Atlantic/Caribbean and Pacific/Nauru tapped distinct mantle sources in Cretaceous time, and (3) the Caribbean basalt province tapped an upper mantle source of Atlantic affinity.

Since present day MORBs from the Atlantic and Pacific are chemically indistinguishable, an interesting corollary of (2) above would be that large scale convective mixing of the mantle sources of the Pacific and Atlantic MORBs must have occurred between Cretaceous and present. Because of the important global implications of our findings, a much larger data base on the Pacific Cretaceous basalts is clearly necessary and is currently being compiled.



GLAUCONITIC SEDIMENTS IN THE NORTHEAST MEXICAN MID-CRETACEOUS: LIMITS IN THE USE OF GLAUCONITE FOR PALAEOGEOGRAPHIC MODELS

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In northeastern Mexico Mid-Cretaceous sediments crop out in barrancas, quarries, and road sections in the Sierra Madre Oriental and in the northern and eastern foothills. The Turonian and Coniacian strata are subdivided lithologically into three units: the Agua Nueva, the San Felipe, and the Mán-dez Formations. The San Felipe Fm. is subdivided into the underlying La Boca Mb. and the overlying Solís Member. As it is a turbiditic sequence, the San Felipe Fm. yields only few fauna: Inoceramids, found in autochthonous beds, prove an age of Middle and Upper Turonian of these sediments from the region between Monterrey/Nuevo León and Cd. Victoria/Tamaulipas.

The distribution of the mineral glauconite in the turbiditic greensands is of great interest in the view of a paleogeographic interpretation of this region. Due to excellent outcrops it could be proved by a bed-by-bed correlation that the turbidites moved from east to west. The distribution of grain sizes of clastic minerals such as quartz, feldspars, and mica served as sedimentologic characteristics as well as the occurrence features of the glauconite: In proximal sections glauconite occurs in grains up to one millimeter in size, whereby this diminishes in vertical as well as in lateral directions to the west, north, and south. At the top of the BOUMA-sequences as well as in distal sections glauconite occurs only as matrix.

Being a phyllosilicate with a hardness of only 2 that will not endure large transport, glauconite has been looked upon as an indicator for nearshore depositional environments. Nevertheless, a transport up to 120 km is possible as shown the investigation of northeast Mexican Mid-Cretaceous sections. It must be considered, however, that the glauconite grains were moved in a suspension in which they were miniaturized and at least, with decreasing energy, precipitated as a gel to the sediment matrix.

Here we find sediments that were originally deposited as greensands at easterly situated island platforms, and then were transported into a westerly situated subsequent trough (Monterrey Basin), caused by movements of the underground or by atmospheric conditions.

The investigations were sponsored by the Universidad Autónoma de Nuevo León Linares through 1982-84 and by the German Research Foundation through 1985-87.

Figure: Compiled Jurassic paleorelief and Late Turonian paleogeography. Stippled areas = cold bottom water. Num. = paleogeographic elements. 3 = Tamaulipas Archipelago.



TECTONIC SIGNIFICANCE OF THE DETERMINATION OF BARIC TYPE FOR ANCHIZONAL AND EPIZONAL ROCKS OF THE ANDES AND CARIBBEAN MOUNTAINS OF VENEZUELA

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Use of the  $b_0$  lattice parameter of dioctahedral potassic white micas as an index of baric type was developed by Sassi and Scolari (1974). This lattice parameter was measured in samples from anchizonal (sub-green schist) and epizonal (greenschist) schists and schists of the Carboniferous Mucochachi and Tostoe formations in the Andes, and upper Cretaceous formations in the Caribbean Mountains of Venezuela. Cumulative frequency curves were developed for 1.) the Mucochachi schists, 2.) Tostoe schists with biotite, 3.) Tostoe schists without biotite, and 4.) schists of the Caribbean Mountains. These cumulative frequency curves were then compared to known terranes to determine baric type. The Mucochachi schists and Tostoe schists with biotite fall at the low end of the baric spectrum and are bracketed by the low-pressure terranes of Bosost and northern New Hampshire. This finding is consistent with the relatively high temperature environment in the Andes which is dominated by thermal rather than baric conditions. Schists of the Caribbean Mountains yield a curve resembling the intermediate pressure terrane of the Swiss Alps. This result is compatible with the metamorphic environment inferred by southward displacement of the Villa de Cura allochthon over the upper Cretaceous rocks of the Caribbean Mountains during the Paleocene. The Tostoe schists without biotite yield a cumulative frequency curve of intermediate to high pressure baric type approaching that of the Otago schists of New Zealand. The Tostoe schists without biotite are commonly assumed to be transitional between lowest greenschist grade Mucochachi schists and high greenschist grade Tostoe schists with biotite, based on the regional geology. The baric indication, in this case, is inconsistent with expected results. Results, therefore, indicate that baric type determination in the Andes and Caribbean Mountains of Venezuela for anchizonal schists and epizonal schists using the  $b_0$  lattice parameter of white micas cannot be used independently in tectonic interpretation, but must incorporate consideration of the regional geology to insure reliability.

# **SLOPE-FAILURE PROCESSES IN SAPROLITIC SOILS OF A TROPICAL RAIN FOREST, PUERTO RICO**

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Rotational failures, with associated downslope earthflow component, appear to be the primary mechanism of hillslope denudation in the rainforest of eastern Puerto Rico. Annual rainfall in excess of 3000 mm, and thick sequences (up to 20 m) of residual soils (saprolite) combine to produce specific failure mechanisms. Shear-strength testing and observations of tension cracks indicate that slope failures initiate by tensile failure of saprolite material. The load on a potential failure plane in the subsurface is thereby increased by the additional weight of the detached block and by saturation of the overlying soil. During or shortly after intense and prolonged precipitation, shear failure then occurs along zones of reduced permeability within the saprolite. Fifty-two "naturally occurring" landslides were mapped using aerial photography and field observation. Although forest elevations exceed 1000 m, the majority of these failures were found between 600 to 800 m in elevation, in areas where there is significant concentration of throughflow. Slope failures show no specific trend with respect to slope aspect. More than 100 "road-related" failures were also mapped and can be attributed to such factors as toe-removal, oversteepening, and increased hydraulic gradients. Tensile stresses in the unsaturated, upper-saprolite zone range from 3 - 10 kPa, and have mean seismic-refraction velocities of 476 m/s (+/- 127 m/s). Denser, clay-rich, less permeable saprolitic zones with mean seismic velocities of 1420 m/s (+/- 157 m/s) indicate probable failure planes where excess pore-water pressure decreases shear strength, leading to shear failure. These zones of translocated clay show marked density increases as shown by an order of magnitude increase in blow counts. Slickenside surfaces in the saprolite are found along relict fractures and joints derived from the parent rock-quartz-diorite, and marine-deposited volcanoclastics. This evidence of differential movement suggests that failures, once initiated, occur along specific planes of weakness in the saprolite. However, the largest landslides (areas greater than 25,000 square meters) fail along the saprolite-weathered bedrock boundary. It is therefore apparent that failure planes occur along zones of contrasting density and permeability within the weathered profile.

# **PETROTECTONIC EVOLUTION OF TOBAGO, WEST INDIES: A FRAGMENT OF A MESOZOIC OCEANIC ISLAND ARC TERRANE**

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The Mesozoic rocks of Tobago can be divided into three main groups: the North Coast Schist (NCS), the ultramafic to mafic plutonic complex, and the Tobago Volcanic Group (TVG). These broad lithologic subdivisions form three east-west-trending belts that transect the island. A mafic dike swarm widely intruded the plutonic complex and TVG, whereas scattered pre-metamorphic and post-metamorphic dikes occur in the NCS belt.

Radiolaria in argillite layers from a distinctive epiclastic unit in the TVG suggest an Albian to Early Cenomanian age (D.L. Jones and P. Noble, pers. comm., 1987), and ammonite molds from this same unit indicate an Albian age (W.A. Cobban, pers. comm., 1988). <sup>40</sup>Ar/<sup>39</sup>Ar hornblende plateau ages from the plutonic-volcanic-dike complex indicate that this rock suite evolved in the Albian (105-103 Ma). The age of the NCS is at least Aptian and perhaps as old as Late Jurassic (<sup>40</sup>Ar/<sup>39</sup>Ar data on relict igneous hornblende from greenschist-facies tuff breccia).

Geochemical and Nd and Sr isotope data demonstrate an oceanic island arc character for all the pre-Cenozoic rocks of the island. All suites span the calc-alkaline and tholeiitic regions on discrimination diagrams. Rare earth element (REE) patterns for the NCS, TVG, and plutonic suite are essentially identical and are moderately LREE-enriched (La/Yb = 1.1-2.7). The dikes exhibit the most unevolved REE patterns, and are interpreted as most closely representative of parental liquid compositions.

Detailed geologic mapping indicates that the NCS was wallrock for the plutonic complex; brittle faulting and retrogression have commonly overprinted these relations, but locally the primary intrusive igneous contact between the plutonic complex and the metamorphosed NCS rocks is preserved. This boundary is a zone of high shear strain where a hot, nearly crystalline mass of ultramafic rocks dynamothermally metamorphosed older greenschist facies rocks during high-level emplacement into the crust.

The pre-Cenozoic rocks of Tobago represent an exceptional cross section through a portion of a composite Mesozoic arc system, other parts of which may be found in the Villa de Cura klippe, the Aruba-Blanquilla island chain, and perhaps the Western Cordillera of Colombia and Ecuador.

# **ASPECTOS TEORICO-PRACTICOS DE LAS INVESTIGACIONES DEL GRADIENTE VERTICAL ANOMALO DEL CAMPO GRAVITATORIO EN EL TERRITORIO DE CUBA**

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## **CHARACTERISTICS OF VOLCANIC CENTERS FROM THE LESSER ANTILLES**

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The active volcanoes of the Lesser Antilles are characterized both by effusive eruptions producing lava flows and domes and by explosive eruptions producing various types of pyroclastic deposits. Five major styles of explosive eruptions have been distinguished, these styles and their products are:

- Pelelean - block and ash flows, dense andesite surges, ash and dust falls;
  - St. Vincent - scoria and ash flows, scoriaceous surges, lapilli-, and ash-falls;
  - Plinian - pumice and ash flows; ash hurricanes, pumiceous surges, lapilli-, and ash-falls;
  - Asama - semi-vesicular block and ash flows;
  - Phreatomagmatic/Phreatic - ash falls, base surges.
- Based on their eruptive products the volcanoes of the Lesser Antilles can be grouped into five types:
- a) Centers composed almost entirely of pyroclastic deposits - Mt. Pelée (Martinique), the Quill (St. Eustatius);
  - b) Centers composed of Pelelean dome clusters and associated aprons of block and ash flow deposits - Saba island, Soufriere Hills (Montserrat);
  - c) Centers with numerous dacitic pumice and ash flows - centers on Dominica, south-central St. Lucia;
  - d) Centers with at least 50% lava flows associated with pyroclastic deposits of various types - the Peak (Nevis), Soufriere (St. Vincent);
  - e) Centers composed of basic lava flows and associated fall deposits - South Soufriere Hills (Montserrat).
- The pyroclastic deposits from all volcanic centers are commonly reworked soon after eruption by fluvial processes so that stratigraphic sections commonly show intercalations of pyroclastic deposits with their epiclastic derivatives. Eruptions from Lesser Antillean volcanoes also produce submarine deposits such as subaqueous ash falls, subaqueous volcanoclastic flows and ash turbidites.

Las investigaciones sobre el gradiente vertical anómalo regional (GVAR) del campo gravitatorio presentan un interés teórico y práctico considerable, ya que permiten, por una parte, incursionar en la elaboración de algunas nuevas formas de resolución de las tareas inversas de la gravimetría durante las investigaciones estructurales regionales, y por otra, asegurar la interpretación correcta de los resultados de los levantamientos gravimétricos de escalas medias y detalladas en las regiones montañosas. Es necesario señalar, que, en la práctica mundial, esta cuestión está poco elaborada, en particular, lo relacionado con el esclarecimiento de las causas del GVAR.

De los análisis teóricos se evidencia que el GVAR puede estar provocado por heterogeneidades locales de la densidad, localizadas tanto en la corteza terrestre, como en el manto superior, así como por zonas características de perturbación de los límites de la corteza y del manto. Los valores del GVAR pueden alcanzar magnitudes significativas (hasta 8-10 mgl/km, según los datos de O.A. Sousin, para las regiones montañosas de Asia) y tener signos diferentes. Magnitudes semejantes de GVAR se destacan también en Cuba Oriental, pero aquí tienen otro significado, ya que están relacionados, probablemente, con una heterogeneidad local de alta densidad y con un levantamiento conforme de la superficie del manto superior. En el trabajo se muestra que para las primeras etapas de las investigaciones del GVAR en Cuba, se debe argumentar con mayor precisión teórica sus magnitudes partiendo de toda la información geofísica y geológica disponible de la región, y después determinar su valor concreto y su distribución areal, primero mediante el análisis de correlación, y posteriormente por investigaciones experimentales. Se menciona también que sin el cálculo de la influencia del GVAR en la parte montañosa de Cuba Oriental se tendrán dificultades serias, no sólo en la interpretación de los trabajos regionales y de búsqueda (en particular, en la búsqueda de cromitas), sino también en la propia confección de los mapas gravimétricos.



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St. Croix and perhaps the bulk of the St. Croix Platform are underlain by a Cretaceous tectonic complex composed almost entirely of volcanogenic sedimentary gravity flows of known Cenomanian or Turonian to Maastrichtian depositional ages. The tectonic complex is a pile of thrust sheets that was assembled before intrusion of late Maastrichtian arc magmas. Each nappe contains two or more deformations. Structures in common among the nappes are folds with initial vergence between S and SW, fold related cleavage, and generally steeply E plunging axes.

The early folds and thrusts of St. Croix's Cretaceous strata are interpreted as a product of offscraping trench wedge deposits at the toe of a Late Cretaceous island arc. Later folding in the tectonic complex records NS horizontal contraction (in today's coordinates), possibly in Paleogene time. The Late Cretaceous island arc which supplied the volcanogenic sediments of St. Croix was active for at least 14 ma and perhaps for over 30 ma.

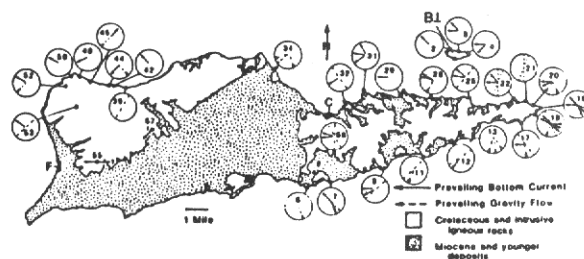
# GRAVITY AND BOTTOM CURRENT FLOW PATTERNS IN UPPER CRETACEOUS ROCKS, ST. CROIX, U.S. VIRGIN ISLANDS - THEIR PALEOGEOGRAPHIC SIGNIFICANCE

STANLEY, DANIEL JEAN, MEDIBA Program, Division of Sedimentology, NMNH, Smithsonian Institution, Washington, D.C. 20560 (USA)

New measurements of sedimentary structures in rocks on St. Croix, U.S. Virgin Islands, record deep-ocean currents in the northeastern part of the Caribbean during the Late Cretaceous. Flow was directed toward the west, a direction parallel to the surface circulation in this region. Paleocurrent analysis of marine volcanoclastic sections of Late Cretaceous age reveals a two-phase depositional pattern: primary emplacement by turbidity currents flowing toward the south, and the subsequent reworking of these layers by W-flowing bottom currents. Sands were first transported to lower slope aprons, and these were then reworked along bathymetric contours by bottom water flow, probably driven by thermohaline processes. At the end of the Cretaceous, the paleo-Atlantic was much narrower and the Caribbean configurations considerably different than at present. The abundance of current-reworked turbidites and bioturbation structures, however, provide clear evidence of active deep water circulation in the tectonically active island arc setting, and the maintenance of oxygenated conditions on the sea floor, as at present.

[Modified from Marine Geology, 79 (1988)]

## DOMINANT PALEOCURRENT PATTERNS, ST. CROIX



Map showing the prevailing paleocurrent directions (tractive bottom current and gravity flow) measured in Upper Cretaceous sequences at 32 localities on St. Croix and Buck Island (B.I.). Geographic names are listed in Table 1. C - Christiansted; F - Frederiksted.

## IMPLICATIONS FROM ST. CROIX ON THE PLATE TECTONIC HISTORY OF THE NORTHEASTERN CARIBBEAN

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Major questions of Cenozoic plate tectonics of the northeastern Caribbean are the duration and total displacement of the Caribbean plate which moves generally east relative to the N. American plate and the precise direction of today's Ca-NA motion. The structural evolution of St. Croix and surroundings implies that the eastern Greater Antilles has undergone transtension since at least early Miocene time and that Ca-NA is more probably ESE than ENE. Troughs between the St. Croix and Virgin Islands Platforms, in the Anegada Gap, and the Puerto Rico Trench may be major breakup zones in this extensional system. Implications of older tectonics from St. Croix are: 1) early Paleogene and/or end Cretaceous NS convergence affected the eastern Greater Antilles, probably due to a downgoing slab at the precursor to the present Puerto Rico Trench; and 2) convergence occurred on the southern wall of the eastern Greater Antilles in the Late Cretaceous, causing the buildup of the accretionary complex that is the Cretaceous basement of St. Croix. The longitudinal history of St. Croix, however, is still unknown.

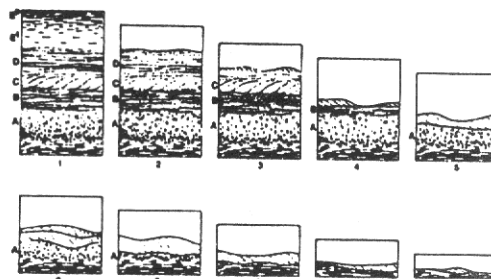
# TURBIDITES, CONTOURITES AND VARIANTS IN UPPER CRETACEOUS STRATA OF ST. CROIX, U.S. VIRGIN ISLANDS - A REVISED SEDIMENTATION MODEL

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A purely turbidite or gravity-emplaced interpretation does not adequately explain the origin of marine volcanoclastic strata in Upper Cretaceous units in St. Croix, U.S. Virgin Islands. Most sandy layers, hereinafter termed intermediate variants, record emplacement in two stages: first by turbidity currents, flowing toward the south, and then a subsequent reworking of these layers by bottom currents flowing toward the west. The sands, accumulating on lower slope aprons, were then displaced along bathymetric contours before burial. A natural continuum of deposits results between downslope-directed turbidity current and bottom current-tractive "sand-mud" deposits. The lower part of a variant layer typically preserves the original graded basal (A) turbidite division, while the texturally cleaner middle and upper parts of such a stratum usually show structures more typically associated with tractive transport. An inventory of the diverse suite of reworked sandy lithofacies in St. Croix may be comparable to other cases in the rock record and modern oceans that involve interaction between gravity-driven flows and bottom currents.

[Modified from Marine Geology, 78(1987)]

## TURBIDITE TO CURRENT-REWORKED SAND CONTINUUM



Scheme showing continuum of sediment types which may result from the reworking of a sandy layer originally emplaced as a complete A-E turbidite (1, at left). Reworking would result in partially eroded (2) and partially remolded turbidite (variant) series (3-7), to completely remolded and entirely forest laminated (8, 9) and to discontinuous starved ripple (10) layers. Burial types 7 to 10 are the reworked "sand-mud" products in this series. Progressive downward erosion and lateral disruption of the original turbidite layer are depicted.

Evolution of siliceous sedimentary environments in the Nicoya Complex (Costa Rica) during the Jurassic-Cretaceous and its relation to the geotectonic development of the Caribbean Crust.

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Recent biostratigraphical and sedimentological studies on the siliceous sedimentary rocks within the ophiolitic Nicoya Complex in NW-Costa Rica yielded a series of new data which shall be presented here.

According to this, three main sedimentary environments belonging to two different basins can be differentiated for these Jurassic to Cretaceous rocks. This is also supported by paleomagnetic data.

Two main sedimentation cycles can be described, one lasting from the Lower Jurassic to the Middle Cretaceous, the other from the Lower to the Upper Cretaceous. The last is partially represented by bituminaceous sediments which may have a relation to the world wide described Cretaceous anoxic events.

Both basins and their sediments present discriminating characteristics that allow a direct correlation with the early geotectonic evolution of the Central American Landbridge and the Caribbean Crust.

Biostratigraphic data based on radiolarian assemblages permit a more concise subdivision of the siliceous strata, thus yielding a precise timescale for the larger regional geologic events. Furtheron they allow a correlation with international zonations.

#### ELEVATED MARINE TERRACES ON NORTHWESTERN PUERTO RICO

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We have undertaken a detailed study of marine terraces on northwestern Puerto Rico focusing on correlation of wave-cut geomorphic features and marine terrace deposit stratigraphy. Stratigraphic control is based on C-14 and U/Th coral dates from three localities; Rincón, Borinquen and Quebradillas. The deposits at these localities are dominantly calcareous sandstones and conglomerates derived from mixed marine and terrigenous sources. Corals occur immediately above unconformities and within the coarser conglomerates. The Rincón area contains the most extensive exposures of marine terrace deposits and has yielded the majority of the dated corals. We have correlated deposits and wave-cut features from all other study sites to the Rincón exposures.

U/Th ages of 114,000 ( $\pm 3,495$ ), 120,000 ( $\pm 2,950$ ) and 120,000 ( $\pm 3,084$ ) YBP were obtained for the 10 m surface at Rincón and Quebradillas. It is generally accepted that sea level was 6 m higher than present approximately 125,000 years ago. Therefore, these data suggest that Puerto Rico has been uplifted at an average rate of 0.034 mm/year during the late Quaternary. C-14 ages of 1,590 ( $\pm 80$ ), 2,050 ( $\pm 80$ ), 1,460 ( $\pm 80$ ) and 1,680 ( $\pm 70$ ) YBP were obtained for the 2 m level at Rincón and Borinquen. U/Th ages obtained for these samples are 3,000 ( $\pm 150$ ), 3,000 ( $\pm 150$ ), 8,000 ( $\pm 470$ ) and 2,000 ( $\pm 118$ ) respectively. These data imply that there was a change in the rate of uplift from 0.034 mm/year to about 1.5 mm/year. There is no reason to suspect that the rates of tectonic uplift should increase so dramatically during the last 1,500 to 3,000 years. However, the possibility of episodic uplift, as opposed to continuous uplift, cannot be ruled out. An alternative explanation to a radical change in the rate of uplift is that local sea level was approximately 2-3 meters higher than present between 1,500 and 3,000 years ago.

Deep-water limestone deposited during the early Pliocene (Quebradillas Formation) is now found at elevations in excess of 100 m in northwestern Puerto Rico. This is in agreement with the average rate of uplift of 0.034 mm/year obtained using dated late Pleistocene marine terrace deposits and suggests that there has been a slow and constant rate of uplift during the last 3 million years.

#### CONTROL DESIGN GRADE TOLERANCE FOR SUCCESSFUL WETLAND RESTORATION

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This paper presents the colonization and growth rate sensitivity to the initial elevation of the planting substrate for an artificially created mangrove wetland.

Located on Naples Bay in the subtropical climate of Southwest Florida, 15 acres of dredge spoil heavily vegetated with Australian Pine (*Casuarina equisetifolia*) were cleared and scraped to an elevation of + 45 cm above 0.0 N.G.V.D. with a construction tolerance of 15 cm above or below the design grade.

Red Mangrove propagules (*Rhizophora Mangle*) 20 - 25 cm in height were then planted 1 meter on center.

The initial monitoring survey, conducted 6 months after planting mangrove propagules documented significant growth rate variability as a function of very minor, 10 - 15 cm, difference in elevation of the initial planting surface.

Planting grades at elevations greater than 50 cm above sea level supported volunteer black mangrove (*Avicennia germinans*) and stunted red mangrove propagule growth.

Planting grades between 35 - 50 cm above sea level supported well developed red mangroves up to 56 cm in height after six months growth.

Planting grades less than 35 cm above sea level suffered high red mangrove propagule mortality. However, in place of red mangrove, substantial oyster and seagrass colonization was recorded.

#### AN EVALUATION OF THE GEOLOGICAL HISTORY AND HYDROCARBON POTENTIAL OF THE LATE MIOCENE-PLIOCENE SEDIMENTS OF THE GOUDRON FIELD - TRINIDAD

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The Goudron Field lies in the Southern Basin onshore Trinidad, on the southeastern flank of the Rock-Dome-Lizard Springs anticlinal trend. A sedimentary sequence of Upper Cretaceous to Late Tertiary sediments has been penetrated by the 174 wells drilled in the area. However, to date only the Late Miocene and Pliocene contain productive hydrocarbon reservoirs.

Two major episodes of late Miocene/Pliocene sedimentation were identified. The older comprised a period of sediment gravity flow into a bathyal environment in the Late Miocene/Early Pliocene and resulted in the deposition of the interbedded shales, silts, sands and conglomerates of the Moruga Formation. The younger comprised a period of fluvio-continental deposition in the Pliocene and resulted in the sands and minor silty clays of the Mayaro Formation.

Deposition of the Moruga Formation was followed by a major tectonic event, resulting in the formation of the Pilote Syncline and the Pre-Mayaro Unconformity. Minor episodes of late Pliocene/Pleistocene faulting are also evident.

The field was discovered in 1927 and has produced 4.7 MMBO to date and may still contain significant reserves to be exploited.

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In the Dominican Republic more than 90 outcrops of Cretaceous and Tertiary rocks were sampled for paleomagnetic investigation. Laboratory work is still in progress. A pilot suite of demagnetized samples from different formations gives following results:

Pre-Aptian volcanic rocks including basalts and quartz keratophyres from the Los Ranchos Formation in the Cordillera del Seibo and the eastern Cordillera Central show a stable remanent magnetization. The uncorrected mean direction  $D = 286.9$ ;  $I = 33.8$  ( $\alpha_{95} = 12.5$ ;  $k = 17.9$ ;  $n = 9$ ) is computed for two localities (distance about 100 km). The directions scatter widely after tilt correction. The data are interpreted to indicate a counterclockwise rotation of the formation after folding of the strata.

Results from the upper Cretaceous EL RIO tonalite batholith in the Cordillera Central coincide with the studies of VINCENT & DASGUPTA (1978). We found a stable direction of  $D = 293.1$ ;  $I = 43.7$  ( $\alpha_{95} = 23.3$ ;  $k = 9.2$ ;  $n = 6$ ). The intrusion seemed to be rotated anticlockwise. The rocks of the Rio Los Baos tonalite north of the Bonao fault carry predominantly secondary magnetization of recent origin, characterized by very low coercitive components.

The Paleocene-early Eocene Imbert Formation is located near the village of Imbert in the Cordillera Septentrional. Stable magnetization components of dual polarity were revealed through progressive thermal and alternating field demagnetization of vitric tuffs from the Rio Obispo section. The corrected directions  $DR = 237.5$ ;  $IR = 19.5$  ( $\alpha_{95} = 9.8$ ;  $k = 47.7$ ;  $n = 6$ ) and  $DR = 61.3$ ;  $IR = -20.1$  ( $\alpha_{95} = 19.7$ ;  $k = 16.1$ ;  $n = 5$ ) suggest a counterclockwise rotation along the Camu fault.

More data from a field trip in spring 1989 will be presented at the conference. They include results from the lower Miocene Soberito Formation and Eocene volcanic and sedimentary rocks of the Sierra de Neiba. First results out of this mountain range display anticlockwise rotations of about 60 degrees.

STRUCTURAL FEATURES ASSOCIATED WITH THE LOS BAJOS FAULT

By

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The Los Bajos Fault is a member of a family of strike-slip faults present in Northern South America. It has an average azimuth of  $113^\circ$ , and a horizontal displacement of roughly ten kilometres.

Structural features present along it depend on changes in the azimuth of the fault. Where this is less than  $113^\circ$ , transpressional features developed, e.g. the East Soldado, Point Fortin and Los Bajos displaced half-anticlines. Where the azimuth is greater than  $113^\circ$ , transtensional features or grabens developed, e.g. the North Soldado and Coora grabens. Sub-perpendicular folds developed away from the fault include the La Brea, Vance River - Boodoosingh, Lot One, Forest, Bernstein and Penal anticlines.

The terminus of the Los Bajos strike-slip fault is the Southern Range Uplift - a basement-involved thrust fault. This basement-involved uplift resulted in the formation of a linear basin - the Columbus Channel Syncline - over its underthrust limb.

STRATIGRAPHY OF BOQUERON BAY

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Seven vibro cores and seismic lines have been used to study the stratigraphy of Holocene deposition in Boqueron Bay, Puerto Rico. Boqueron Bay is a 10 square km area bay on the southern west coast of Puerto Rico. It is a shallow bay (10 m depth), bounded on three sides by land and restricted on the fourth side (west) by a shoal reef, which restricts circulation to the open sea to a narrow channel at the north and the south margins of the bay.

The surface sediments are dominantly skeletal carbonate except for a terrigenous quartz-rich component at the west and northwest. The cores show several episodes of mollusc sediments layers, possibly indicating rapidly changing environmental conditions. The cores and seismic lines are used to develop a three-dimensional pattern of deposition during Holocene sea transgression.

HOLOCENE OSTRACODA IN AND AROUND LAKE ENRIQUILLO (DOMINICAN REPUBLIC)

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Fifteen cores of generally about 30-cm length, taken in Lake Enriquillo by Paul Mann, Charlotte Glenn and Rose Maddox (University of Texas, Austin, and University of Houston), show ostracode faunas of very low diversity, but occasionally great abundance of certain species. The top 10-15 cm of four cores exhibits a dominance of *Cypridella salebrosa* Bold, accompanied by *Limnocythere floridensis* Keyser, indicating very low salinity, possibly caused by the presence of fresh water springs. The most common assemblage, occurring in the deeper parts of all cores, and occasionally throughout the cores, is dominated by *Cypridella adentata* (Klie), *Dolerocypris inopinata* Klie and *Perissocytheridea cribrata* (Klie). This assemblage is almost identical to the one described by Klie from the saline lagoons of Aruba, Bonaire and Curaçao, and indicates hypersaline conditions, in agreement with the 49 ‰ salinity reported from the lake. Between these two extremes and occupying the middle (and sometimes the upper part) of the cores is an assemblage of *Cypridella similis* (Brady) with *Dolerocypris inopinata* and *Perissocytheridea cribrata*. The faunas of the subaerially exposed sediments overlying the Holocene reef around Lake Enriquillo are very different from the faunas of the cores. The basal beds have an almost normal marine fauna with some additional brackish water species (*Cypridella similis*, *C. salebrosa* and *Perissocytheridea cribrata*). The overlying beds rapidly become more limnic (folligohaline), with *Cypridella salebrosa*, *Limnocythere floridensis* and *Cytheridella holdi* Purper. Intermediate beds yield *Cypridella similis*, *C. mexicana* Sandberg and *Perissocytheridea salipunctata* (Brady), indicating intermediate salinities (mesohaline). The *Cypridella salebrosa* assemblage of the bottom part of a 115-cm-long core in the lake might belong to the similar fauna near the top of the exposed sections, as does the assemblage of a limestone on Isla Cabritos in the lake.

SHORT REVIEW OF THE OSTRACODA OF THE MONTPELIER  
AND COASTAL GROUPS OF JAMAICA

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The Montpelier Group (Oligocene - Middle Miocene) contains a mixture of dominant bathyal species, minor outer neritic ones and rare inner neritic taxa. The neritic forms are probably derived from contemporaneous deposits on the shelf. However, in the basal Spring Garden Formation (N 8) redeposited specimens are derived from older (N 1-2) shallow water sediments. The amount of neritic taxa increases slightly in the middle Bonny Gate Formation (N 11), and in the lower Buff Bay Formation (N 14), and there is a steady increase of neritic forms from late Middle Miocene (N 15) to Pleistocene, when more than 75% of the species are neritic. Due to the small number of shallow water species from Oligocene to Late Miocene, it is not surprising that the application of the zonation based on shallow water Ostracoda is not quite satisfactory.

GEOCHEMISTRY OF THE SAN JUAN BASALTS, DOMINICAN  
REPUBLIC: A REAPPRAISAL BASED ON NEW TRACE ELEMENT  
DATA

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Basalt lavas of probable Pleistocene age from the northwestern San Juan valley are nepheline basalts, basanites, and alkali olivine basalts. Eleven new samples were analyzed for major elements and for Cr, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, Ba, and Rare Earth Elements (REE).

The San Juan basalts are enriched in LIL elements including Ba: 1078-2336 ppm and Sr: 1586-3466 ppm. Rb/Sr ratios are less than .04. Sr87/Sr86 ratios range from .7059 to .7079, and are higher than calc-alkaline basaltic rocks of similar age in the Valle Nuevo, Padre Las Casas, Yayas de Viajama regions of the eastern Cordillera Central. The San Juan basalts also differ from the calc-alkaline basaltic rocks of the Cordillera Central in having high concentrations of HFS elements (Ti, Nb, Zr) including Nb: 10-77 ppm; Zr: 163-435 ppm, and TiO2: 1-4.1 weight percent.

REE patterns are highly fractionated with chondrite normalized La/Yb ratios ranging from 46 to 85, and La/Sm ratios ranging from 8 to 10. There is minimal enrichment of LIL elements to LRE elements as evidenced by chondrite normalized Ba/La ratios ranging from 1 to 1.5. The behavior of Sr, Ce, La, and Zr is closely related in these basalts.

Numerical petrogenetic models indicate that key processes involved in the origin of these basalts include variable degrees of partial melting of an enriched mantle source region and fractional crystallization.

STRUCTURE DE LA MARGE S-W CARAIBE  
(secteur Cartagena, Colombie)

par

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Les profils sismiques obtenus au cours de la campagne DIAPICAR (oct.-nov. 1987) sur la marge SW caraïbe entre le golfe de Morrosquillo et l'embouchure du Magdalena montre l'existence de deux secteurs aux caractères différents :

1) Au Sud, un front de déformation englobant plate-forme et telus continental. Ce front est constitué par une série de plis, rides et dômes d'origine diapirique dont la distribution est en relation étroite avec la structuration régionale de direction principale N30°.

Vers 10°25 de latitude Nord, la base de ce front de déformation s'incurve brusquement à N90° en direction du continent ; c'est une zone de transition où la présence de deux directions structures majeures (N30° pour le banc Tortuga et le presqu'île Baru, N90° pour le chapelet d'îles du Rosaire, cours en dent de scie du Dique) soulignent l'existence de mouvements cisailants.

2) Au nord, une immense accumulation d'origine deltaïque et qui peut être subdivisée en un éventail fossile centré sur Galerazamba et un prodelta Actuel où les manifestations diapiriques rencontrées sont d'un type différent de celles du secteur Sud.

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GEOLOGICAL EVOLUTION OF THE CRETACEOUS AGE SEDIMENTS OF  
THE SABA BANK AREA AND THEIR PETROLEUM POTENTIAL

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The Saba Bank area belongs to the very complex tectonic framework of the Caribbean Plate and so far no completely satisfactory theory of the tectonic history of the region exists. In formulating a thesis of the area's history, three (3) ideas must be considered: (1) Is Saba Bank genetically related to the Greater Antilles, the Lesser Antilles or a little of both? (2) Is the Saba Bank a northern extension of the Aves Ridge? (3) Do sediments of Early Eocene age and older exist beneath the Saba Bank Platform? During February of 1988 Western Geophysical conducted a seismic survey over the western portion of the Saba Bank. The new seismic revealed that a thick sedimentary section exists below what had been previously considered economic basement. The reworked Cretaceous Age coals and nanofossils found in the Tertiary sediments in both wells drilled on the platform prove that the Cretaceous rocks will not be of deep marine origin. Offshore St. Croix a thick sequence of sandstones and conglomerates has been found. This sequence has not been dated but from its stratigraphic position it should be Mid Cretaceous. These sediments are direct evidence that thick nonmarine Cretaceous sediments do exist in the area. These sediments dip 10 to 20 degrees to the west which, when extrapolated to the east, place them under the Saba Bank Platform. The migrated hydrocarbons found in both Saba Bank wells showed that source rocks exist in the area. Both the seismic data and the well data suggest that a thick nonmarine untested Cretaceous sedimentary section exists under the Saba Bank.

# COAL EXPLORATION IN COSTA RICA: A CASE STUDY

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Energy-planning, growth and development problems in Central America cannot be solved without a better understanding of indigenous energy resources. Developed peat and coal resources can be utilized in a variety of ways, ranging from domestic use through process heat for the coffee, sugar and cement-making industries, and for the generation of electricity. Beginning in 1983, the Costa Rican government and the US Agency for International Development (AID) sponsored a cooperative coal development program using United States Geological Survey (USGS) and Refinadora Costarricense de Petroleo (RECOPE) geologists. USGS scientists assisted RECOPE geologists in coal exploration and resource assessment activities with emphasis on technology transfer.

Accomplishments of the formal cooperative program include: A) reconnaissance stage investigations were completed in five coal areas (Esparza, Puriscal, El Tablazo, Rio Estrella, and Upala), B) reconnaissance stage investigations and early exploration stage studies were underway in the Zent and Venado coal fields, and C) the first exploratory drill-hole program in the Uatsi Project area of the Baja Talamanca coal field had been completed and a summary progress report had been prepared. As part of the original cooperative agreement, the USGS and USAID helped RECOPE with training and equipment to establish a modern coal analytical facility, designed to provide definitive information on coal quality factors of the coals in Costa Rica.

Since the end of the formal program, RECOPE has continued exploration and development of the Zent coalfield because it is located near main railway and highway systems and could be the source of coal for industries located in the central part of Costa Rica and exploration and development for the Uatsi Project area because of the need for increased electric-generating capacity in that part of the country.

Results to date include: A) the establishment of coal resources of lignite and subbituminous rank of more than 49 million metric tons, of which more than 32 million metric tons are in the Uatsi Project area, almost 15 million metric tons in the Zent coal field B) 700 metric tons of coal were recovered at a surface mining operation in the Zent coal field for testing as a supplemental fuel replacing fuel oil in a cement-making plant C) testing programs for cleaning of coal and improving quality have been conducted and D) preliminary mining designs have been prepared for areas in both the Zent coal field and the Uatsi Project area. As the exploration continues, it is expected that the estimated resources will increase. Planning for further development activities has continued. Coal related hydrologic studies, refraction seismic exploration, and more core-drilling are all planned for the near future.

## BEACH DYNAMICS IN THE SAN JUAN METROPOLITAN AREA

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The north coast of Puerto Rico is a microtidal, high energy environment with a series of separate lunate embayments formed behind eroded collanites. To quantify the dynamic nature of the beaches in the San Juan area, twenty-four beach sites were profiled on a bi-monthly basis from fall of 1984 through fall of 1985. Wave climate changed over the year with the impact of swells from two tropical storms, Gloria and Kate, being documented. Over the year, eight of the profile stations experienced net losses, with erosion rates in the range of .3 to 11 m/yr; the other sixteen stations were either stable or accreting. In general, areas of wave convergence had the most mobile beaches with low net erosion rates.

Seasonally changing wave energy interacts with the complex bathymetry resulting in little lateral continuity of incident wave energy along any given stretch of shoreline. A variety of seawalls, groins, and jetties have been built to further add to the heterogeneity of the San Juan shoreline. Irregular offshore bathymetry commonly focused incident wave energy into various sections of the embayments and away from the headlands. Results of wave refraction modeling indicated greater potential longshore transport in the embayments than on the headlands. Thus, the vulnerability of a particular beach depended primarily on its position in relation to the foci of wave energy generated by mean and extreme wave conditions.

Each beach reacted differently to periods of extreme wave conditions. In response to the swells generated by Hurricane Gloria in September 1985, eight beaches accreted while ten showed losses. Two months later, Hurricane Kate produced similar responses but on different beaches. Those beaches that had a natural low tide sill near shore were the most stable under any wave condition. Future wave climatology will be the determining factor in the continuing evolution of the beaches in the San Juan area. Measures to mitigate erosion may include perched beaches and possibly engineering solutions involving modification of the offshore collanites to modify the amount of wave energy entering the area and the refraction patterns developed.

PETROLOGY OF THE LOWER CRETACEOUS VOLCANIC ROCKS OF NORTHEASTERN PUERTO RICO - INITIAL PRODUCTS OF ISLAND-ARC SUBDUCTION  
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The Lower Cretaceous pre-Robles formations are the oldest exposed rocks of the central volcanic-plutonic core of Puerto Rico. In northeastern Puerto Rico, pre-Robles rocks include the Dagua Formation at the base, the Figueroa Lava and the Fajardo Formation. The Dagua Formation consists of predominantly volcanic breccias, lava flows and tuff. Low silica contents, abundant diopside-augite phenocrysts, common olivine pseudomorphs and calcic plagioclase compositions indicate that these rocks are basalts and basaltic andesites. The Figueroa Lava is a thick sequence of albite-rich andesitic and dacitic lava flows with only minor interbedded volcaniclastic rocks. Clear homogeneous albite phenocrysts in these rocks apparently formed during burial metamorphism. The lower Fajardo deposits consist of silicic volcanic breccias and volcaniclastic deposits which represent a continuation in the silica-enrichment trend defined by the underlying Figueroa samples. By contrast, the interbedded flows and younger volcaniclastic rocks of the Fajardo Formation record a change to pyroxene-rich intermediate compositions.

Based on whole-rock compositions, modal and normative mineralogy and mineral compositions, the pre-Robles volcanic rocks of northeastern Puerto Rico are subalkaline tholeiites. The low  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of whole-rock samples, the Cr-rich cores of clinopyroxene phenocrysts, and the similarity between the pre-Robles basalts and experimentally-produced melts of peridotite, indicate that the pre-Robles magmas were probably derived from the partial melting of mantle peridotite. Much of the geochemical and mineralogical variation found in the pre-Robles samples appears related to subsequent crystal fractionation at two or more levels within the crust and upper mantle. Evidence that the silicic and intermediate volcanic rocks were derived from mafic magmas by shallow-level fractionation includes: 1) geochemical trends defined by whole-rock and mineral compositions; 2) temporal relationships of individual flows; and 3) good fit of computer-derived fractionation models.

## SIGNIFICANCE OF PYROXENE-RICH UNDERSATURATED BASALTS IN THE EARLY TECTONIC EVOLUTION OF PUERTO RICO

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A recent petrographic and geochemical study of volcanic rocks in the Lower Cretaceous formations of central Puerto Rico has located several pyroxene-rich/plagioclase-depleted undersaturated basalts within a thick sequence of less-mafic plagioclase-rich subalkaline lava flows and pyroclastic rocks. These slightly-alkalic undersaturated volcanic rocks include several lava flows, volcanic breccias and tuffs in the partially-correlative Jayuya Tuff, Torrecilla Breccia, and Pitahaya Formation of the central tectonic-stratigraphic block of the island. The general absence of plagioclase phenocrysts, Cr-rich diopside compositions of pyroxene phenocrysts, high Ni and Cr whole-rock concentrations, high modal concentrations of olivine and clinopyroxene phenocrysts, and normative concentrations of olivine and hypersthene or nepheline in these rocks indicate that they originated from deeper crustal levels than other Lower Cretaceous volcanic rocks of Puerto Rico.

The undersaturated volcanic rocks are located within a stratigraphic sequence that records a rapid change in water depth. Adjacent shallow-marine limestones, interbedded calcareous units with shallow-marine fossils, and possible oxidized units within the sequence indicate that these rocks were erupted in shallow-marine or subaerial conditions. In contrast, the overlying Robles Formation was deposited in predominantly deep-water conditions. Therefore, it appears likely that the pyroxene-rich rocks were erupted concurrently with formation of deep-seated faults that accommodated much of the subsidence in this area.

Based on overlapping whole-rock, mineral and isotopic compositions between the pyroxene-rich undersaturated rocks and the plagioclase-rich subalkaline rocks, both types appear to have been derived from a similar magmatic source but underwent different crystallization histories. The undersaturated basalts apparently were subjected to deep-level fractional crystallization where plagioclase was not a stable phase. In contrast, the underlying and interbedded plagioclase-rich volcanic rocks of the Lower Cretaceous formations must have undergone extensive shallow-level fractionation. The undersaturated basalts were probably erupted during an episode of crustal faulting and subsidence. These rocks appear to have moved rapidly through the crust along deep-seated faults, thereby preventing extensive shallow-level crystallization.

#### MAP OF MODERN REEFS AND SEDIMENTS OF ANTIGUA, WEST INDIES

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A colored geologic map of the submarine geology around Antigua is 70.5 x 103 cm (27.75 x 40.5 in) in size, with a scale of 1:40,000. The reefs and bottom sediments are mapped to a depth of about 20 m (10 fms). Five main submarine geologic units are mapped: 1) grass-held sediment, 2) linear reefs, 3) patch reefs, 4) deeper reefs, and 5) sand. Sixteen divisions of these main types are also shown. The coast of Antigua and its nearby islands is distinguished by symbols as rocky, sand beach or mangrove fringe. Certain special features, such as steep scarps, sand-filled channels in coral, and underwater bedrock outcrops are also shown.

The map was constructed photogrammetrically on a stereoplotter, with "ground-truthing" accomplished by swimming traverses, observations and sampling from boats, inspection from the shore, and some drilling. The various seafloor environments/communities are described and illustrated in color on the back of the map.

A special feature is the recognition of changes in bottom environments over time; 49 such areas are mapped, and the nature of the changes described. The sizes of such areas are also tabulated. Most show the effects of commercial and residential development on Antigua since World War II.

Looking to the future, the map will serve as a benchmark of shallow-water environments against which to compare future observations and mapping.

#### MULTIPLE TRANSPORT HISTORY OF MINERAL SANDS ON THE SOUTH JAMAICAN COAST DEDUCED FROM PROVENANCE, SURFACE TEXTURE AND SEA-LEVEL STUDIES

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Mineralogically mature sediments are rare in the Jamaican rock record, reflecting generally short transport distances from source to depositional site. An exception to this are the quartz-rich sand deposits of the Black River basin on the south west coast of the island. Provenance studies suggest that these sands are derived from the Cretaceous Central Inlier. Consideration of transport pathways indicates that drainage from the inlier to the south coast occurs through the Rio Minho river, the mouth of which reaches the shoreline c. 60 km east of the Black River area. Surface textures revealed by S.E.M. include evidence of both marine and eolian influences, the latter commonly overprinting the former. Movement westwards along the island shelf, which extends over 25 km south of the island at an average depth of about 40 m could have been facilitated by dominant westerly current and littoral drift directions, after deposition from the Rio Minho. Emplacement of these sediments, which clearly were extensively winnowed during shelf transport, must post date the last interglacial event, because the sands overlie an elevated reef of this age at the present shoreline. Sea-level lowering during the Wisconsinan exposed the shelf for an extended period during which time characteristic south-east winds transported the sands to their present location. This proposed fluvial, marine and eolian history has important implications for mineral exploration, because it suggests that the south coast shelf of the island may be extensively veneered by mineral deposits. Metallic minerals found on the shoreline between the Rio Minho and Black River add extra significance to this possibility.